**BURSA TECHNICAL UNIVERSITY ❖ GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES**

# INDOOR LOCATION FINDING OF THE TRANSMITTER BASED ON BLUETOOTH RECEIVED SIGNAL STRENGTH

**M. Sc. THESIS**

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**DECEMBER 2018**

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**DECEMBER 2018**

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## PLAGIARISM DECLARATION

In this thesis, I declare that all information and results presented in visual, audio and written form have been obtained by me in compliance with academic and ethical rules. I declare that, all results and information in this thesis which are not specific to this study have been documented with sources and in the contrary case, I accept all kinds of legal results.

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Signature:

## FOREWORD


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## ABBREVIATIONS

| | |
|---|---|
| **AOA** | : Angle of Arrivals |
| **AP** | : Access Point |
| **BLE** | : Bluetooth Low Energy |
| **GPS** | : Global Positioning System |
| **GNSS** | : Global Navigation Satellite System |
| **IPS** | : Indoor Positioning Systems |
| **JSON** | : Java Object Notation |
| **LOS** | : Line of Sight |
| **LTE** | : Long Term Evaluation |
| **LLS** | : Linear Least Squares |
| **NLOS** | : Non-Light of Sight |
| **NLS** | : Nonlinear Least Squares |
| **RF** | : Radio Frequency |
| **RFID** | : Radio Frequency Identification |
| **RSSI** | : Received Signal Strength Indicator |
| **RTLS** | : Real Time Location System |
| **SVM** | : Support Vector Mchine |
| **TDOA** | : Time Difference of Arrival |
| **TOA** | : Time of Arrival |
| **TOF** | : Time of Flight |
| **UWB** | : Ultra Wideband |
| **UUID** | : Universally Unique Identifier |
| **VLC** | : Visual Light Communication |
| **WCF** | : Windows Communication Foundation |
| **Wi-Fi** | : Wireless Fidelity |
| **WLAN** | : Wireless Local Area Network |

## SYMBOLS

| | |
|---|---|
| $A_i$ | : One meter RSSI value |
| $A$ | : Linear Least Square matrix |
| $d$ | : Distance |
| $h_r$ | : Receiver antenna height |
| $h_t$ | : Transmitter antenna height |
| $J$ | : Jacobian matrix |
| $J^T$ | : Transpose of Jacobian matrix |
| $n$ | : Path loss exponent |
| $P_r$ | : Received power |
| $P_t$ | : Transmitted power |
| $G_r$ | : Receiver antenna gain |
| $G_t$ | : Transmitter antenna gain |
| $r_1,r_2,r_3$ | : Radius of three APs |
| $x_1,x_2,x_3$ | : x-Axis coordinates |
| $y_1,y_2,y_3$ | : y-Axis coordinates |
| $z_1,z_2,z_3$ | : z-Axis coordinates |
| $x_b,y_b$ | : Coordinates of Beacon |
| $\sigma$ | : Standard Deviation |
| $\lambda$ | : Wavelength in meter |

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**INDOOR LOCATION FINDING OF THE TRANSMITTER BASED ON BLUETOOTH RECEIVED SIGNAL STRENGTH**

## SUMMARY

Around the world, positioning in open environments is done via satellites. Generally, these systems are called Global Navigation Satellite Systems (GNSS). The most widely used GNSS is the Global Positioning System (GPS). GLONASS and Galileo are other GNSS systems which are used in Europe and Russia. Satellite positioning systems require a direct line of sight (LOS) with satellites to provide high accuracy. The GPS sensitivity can be reduced by a few meters in open areas. Due to physical objects like doors, walls of buildings, potential interference sources like electronic equipment, electrical sources, metal objects, it is almost impossible to use satellite positioning systems in indoor environment thus Indoor Positioning Systems (IPS) are being developed. In this thesis, we implement an Indoor Positioning System based on Bluetooth Smart Technology for signaling between transmitter and receivers. Besides, Trilateration and Linear Least Squares methods are used to determine the position of the transmitter together with the radio received signal strength. The estimated values are optimized by the Newton Raphson iteration method. The analysis of the results shows that the achieving mean errors is between 0.11 to 2.2 meters for stationary devices in a large-size laboratory. In the implemented system person of interests or items are not required to possess mobile devices, it is enough to carry Bluetooth Beacon devices which are cheap and efficient in terms of power consumption.

**Key words:** Bluetooth, Indoor Positioning, RSSI, Trilateration, Linear Least Squares, Newton Raphson

# ALGILANAN BLUETOOTH SİNYAL GÜCÜ İLE İÇ MEKANLARDA SİNYAL KAYNAĞININ KONUM TESPİTİNİN YAPILMASI

## ÖZET

Açık ortamlarda konum takibi tüm dünyada uydular aracılığıyla yapılmaktadır. Genel olarak bu sistemlere Küresel Uydu Seyrüsefer Sistemi (GNSS) adı verilir. En yaygın kullanılan GNSS Küresel Konumlama Sistemi (GPS) 'dir. GLONASS ve Galileo, Avrupa ve Rusya'da kullanılan diğer GNSS sistemleridir. Uydu konumlandırma sistemleri, yüksek doğruluk sağlamak için uydularla doğrudan görüş hattı (LOS) gerektirmektedir. Açık alanlarda GPS hassasiyeti birkaç metreye kadar düşebilmektedir. Kapılar, binaların duvarları gibi fiziksel nesneler, elektronik cihazlar, elektrik kaynakları, metal nesneler gibi potansiyel bozucuların bulunması nedeniyle iç ortamda uydu konumlandırma sistemlerini kullanmak neredeyse imkânsızdır ve İç Mekân Konumlandırma Sistemleri (IPS) geliştirilmektedir. Tez çalışmasında, verici ve alıcılar arasında sinyal gönderimi Bluetooth Smart teknolojisine dayanan bir iç mekan konumlandırma sistemi uygulanmıştır. Ayrıca vericinin konumunun belirlenmesinde, algılanan sinyal gücü değeriyle beraber Trilaterasyon ve En Küçük Kareler yöntemleri kullanılmıştır. Elde edilen tahmin değerleri Newton Raphson iterasyon yöntemi ile optimize edilmiştir. Sonuçların analizi büyük ölçekli bir laboratuvarda durağan cihazlar için ulaşılan ortamala hatanın 0.11 ile 2.2 metre arasında olduğunu göstermiştir. Gerçekleştirilen sistemde, ilgili kişilerin veya öğelerin mobil cihazlara sahip olması gerekli değildir, güç tüketimi açısından verimli ve ucuz olan Bluetooth Beacon cihazlarını taşımak yeterlidir.

**Anahtar Kelimeler:** Bluetooth, İç mekan konumlandırma, RSSI, Trilaterasyon, En Küçük Kareler, Newton Raphson

# 1. INTRODUCTION

In recent years, the rapid developments in technology have provided daily use of many technologies that were formerly used at the military level. Outdoor positioning is based on satellites like GPS, GLONASS, GALILEO and there are many applications and consumer products for personal, vehicle, pet, object tracking. GPS tracking is the best known among the satellite tracking systems.

Satellite positioning is completely free and a small hand-held terminal is sufficient for tracking. If you want to use it in different applications, then you have to pay to the service provider. There is no precise method for indoor positioning such as GPS with high accuracy. The reason is the non-line of sight conditions, high attenuation, severe multipath and signal scattering, fast temporal changes due to indoor environment conditions, high demand for accuracy and precision, characteristics of transmitters and receivers. Because of the reasons mentioned, a different positioning system is used for indoor position tracking. The system is called Indoor Positioning System (IPS) and this is used for locating objects or people inside a building by using magnetic fields, acoustic signals, radio waves, or other sensory information collected by mobile devices [1] and access points. IPSs are based on Wi-Fi, RFID, Bluetooth, Ultrasound, VLC and Ultra Wide Band, sensor technologies and there are many application areas related to the subject like smart factories, hospitals. There are indoor navigation systems for the hearing and visually impaired person, patient tracking, locating device through buildings, aiding tourists in museums, tracking kids in crowded places and tracking expensive equipments.

The main goal of this research is to learn detailed information about indoor localization and develop an indoor positioning system based on BLE 4.0 technology which is suitable for dynamic environments, portable; means applicable to different indoor scenarios, adaptive and has low cost. This master thesis is composed of three parts. First part provides background information which is the theoretical foundations for other parts. This is literature review and positioning details in which all detailed informations about the techniques, technologies, methods, algorithms and implementation approaches of indoor positioning are given. Test environment and installation of the BLE based indoor positioning system, hardware and software details, calibration phase, data collection and analysis, methods used, tests performed and results are included in the second part of the study. In the last part the conclusion and future works are mentioned.

# 2. LITERATURE REVIEW

Today, applications about indoor positioning are expanding continuously and position determination is performed via smart devices [2]. Sensor nodes became smaller, intelligent and by the help of the networking capabilities they are spreaded. There is not a strict way, there are different wireless technologies and any of them can be used.

RFID is one of the most popuplar localization technology found in literature review. Particularly, 2D studies are performed generally and sufficient accuracy can not be reached with this system. A 3D implementation approach for improving accuracy with RFID is purposed as a solution [3]. RFID-based RTLS systems are also available today, especially being used in hospitals and factories. With these systems, it is possible to determine the location in room-level.

Zigbee is also popular for indoor studies. There are examples in literature in which Zigbee technology is used with different techniques. In a study an indoor positioning system based on RSSIs and fingerprinting using ZigBee technology was conducted [4]. Another ZigBee based indoor location system uses k-nearest neighbor algorithm with real time RSSI to calculate mobile node's position [5]. Generally indoor positioning systems use WLAN infrastructure deployed in buildings. The signal strength of the Wi-Fi was used in a study to estimate the location of the people indoor. Three APs are positioned similar to the GPS concept and trilateration technique is used for positioning [6]. There is an example for ultra wideband technology usage in indoor positioning. In the scope of this paper [7] a SWOT analysis was performed that identifies strength, weakness, threats and opportunities that affect UWB technology.

There is a master thesis which explains the details of indoor positioning that uses RSSI of Bluetooth Smart in the literature. This is a useful work that evaluates four different algorithms which are trilateration, iterative trilateration, a partical filter and a fingerprinting [8]. In the literature survey, many thesis and papers based on Bluetooth have been found [9,10,11]. A study presents a system that uses Bluetooth signals with trilateration achives mean errors around 1 to 3 meters [12].

There is another study that finds the location of patients' by using BLE technology in the hospital environment through the signal values taken by mobile application.Their positioning algorithm has 97.22% accuracy [13].

In the recent years, studies related to the subject matter has also increased in Turkey. In the literature survey, a new algorithm consisting of differential power analysis and continuous signal effect is proposed for closed area positioning optimization on a grid-based fingerprinting algorithms by using existing Wi-Fi infrastructure for a mobile device [14].

Generally studies are focused on mobile devices – mobile devices determine the location of the person of interest (POI) [15,16]. However, in this thesis, the POI's are not required to possess mobile devices but to carry Bluetooth beacon devices which are extremely cheap compared to mobile devices. POI's will carry beacons and Raspberry-Pi based Wi-Fi Hotspots will relay this information to the server.

The performance of the generated systems depends on many parameters. Some parameters are listed below; The most important among these parameters is accuracy, which is the mean distance error between the estimated location and the actual location of the device. This depends on the technology, radio propagation characteristics of the environment, the technique that is used for estimation. The higher accuracy means better system.

RF signal behavior is an important parameter. Especially in Wi-Fi based positioning systems, result is directly influenced by the signal behavior [17].

Signal behaviors are; absorption, reflection, diffraction, breakage.

Signal behavior reasons; indoor environment, antenna effect, human existence, access point density and placement.

Signal behavior results; multi dimensional damping, shadowing, signal path loss, tunnel effect.

Other metric is precision. This is the probability of successful or unsuccessful location estimates within a given accuracy. Calibration complexity is another metric that is the hardware and software implementation of the system and it should be easy to install and setup. Scalability character is an important metric. The positioning system should be easily extensible when the scope of the positioning gets larger based on geography and number of users. Cost metric of the system depends on money, time, space, weight and energy. These factors are important in different levels of the system which are installation and maintenance, infrastructure components, and positioning devices [18]. Robustness and Adaptability is also another metric.  The positioning system should continue to function reliably without being greatly affected by the changes that may occur in the environment and without requiring major reconfigurations. Integrity metric is the output confidentiality of the localization system. Difference between the estimated location and actual location should be in acceptable value if there is any malfunction. The system should be portable and it can be used in different scenarios. Coverage area metric refers to the area covered by the system. Indoor localization systems have local coverage means that covers a limited area. This system can be scaled by adding new hardware devices.

# 3. INDOOR POSITIONING DETAILS

## 3.1 Technologies

Different technologies are used for locating the indoor position. When researches are examined, it is observed that the most popular technologies are Wi-Fi, Bluetooth and RFID. But besides these, there are many studies with the technologies like UWB, Zigbee, the sensors like accelerometer, gyroscope, magnetometer or studies in which technologies are used together that is called hybrid technologies [19]. Following Figure 3.1 shows the technologies which are using for indoor positioning.

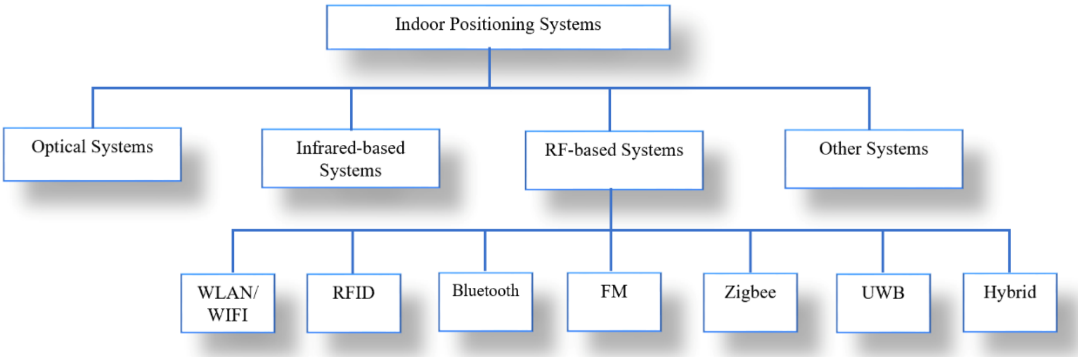



**Figure 3.1:** Indoor positioning technologies

In this thesis, we are focused on Bluetooth wireless technology by considering the advantages that will be explained in the following sections.

### 3.1.1 Wireless Fidelity (Wi-Fi)

Wi-Fi is the common name of the IEEE 802.11 standard. Wireless can be connected to an existing Internet network by means of Wi-Fi technology in the tablet, telephone, computer, smart devices. Communication over the wireless network is done in two directions. The wireless adapter of a device converts radio signals into a transmitter and sends it through an antenna. The wireless router receives the signal and decodes it, then sends the information to the internet using the physical wired Ethernet link. The process works the same in reverse. Each wireless router broadcasts a signal which is received by devices within a specific area. These devices have ability to measure signal strength. Once the devices are connected wirelessly to the access point that emits this signal, they can communicate with the AP no matter where they are in indoor environment. Figure 3.2 demonstrates the Wi-Fi based mobile system.

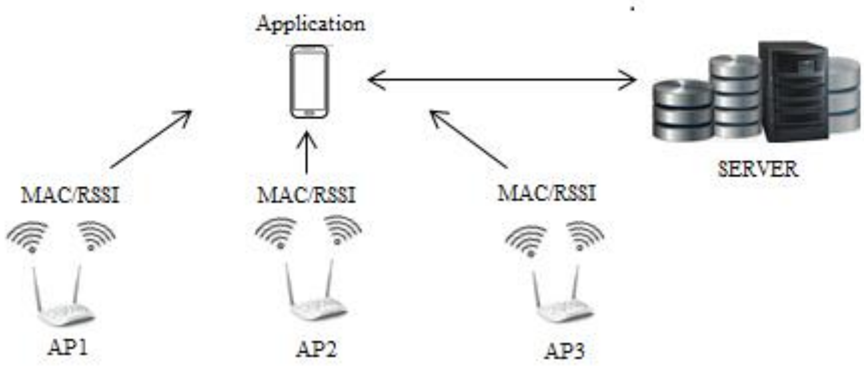



**Figure 3.2:** Wi-Fi based indoor positioning

Wi-Fi is available in many places like houses, airports, office buildings etc. Also, it has a low cost and high coverage advantages over other technologies. Because of these reasons this technology is commonly used in indoor positioning.

In literature, there are many different studies about Wi-Fi positioning. A master thesis [16] found the position by using Wi-Fi technology with fingerprinting in an airport. Particle and Kalman filter were used for eliminating signal fluctuation.

Wi-Fi with fingerprinting is popular and there is a study which gives another solution to increase the accuracy which is called Dynamic Fingerprinting [20]. In this system when a passive user becomes stationary, system creates a fingerprint with this user location information.

The Wi-Fi signals are affected due to the indoor environment conditions [17], so a new algorithm presented which is called FMA-RRSS (Fingerprint Matching Algorithm Based on Relative Received Strength Signal) [21]. This algorithm is a new position-determined model in which the location is found from RSSI values of Wi-Fi signal.

### 3.1.2 RFID

RFID is a system used to transmit serial recognition information of an object or a person wirelessly with radio waves. The data is carried on the transponder. The system consists of two parts as receiver and transmitter. Data exchange between the two devices is provided by magnetic or electromagnetic fields. The reader loads energy into the antenna to receive the data stored in the memory of the carrier. In this way, the antenna radiates the radio signals and activates the carrier. The active carrier also leaves the data in memory [15].

RFID tags can be programmed to receive, store and send object information. RFID carriers are analyzed in three general categories as active, passive and semi-passive according to the source of electrical power. Active carriers usually have their own power sources, which they obtain from a pulse. Passive and semi-passive carriers take their strength from the reader's signal [22].

For semi-passive labels, a small battery is added for increasing the broadcasting signal strength. These labels with a larger reading area are more reliable and can respond more quickly to the reader. The operational logic of RFID tags is shown in the following schematic Figure 3.3.

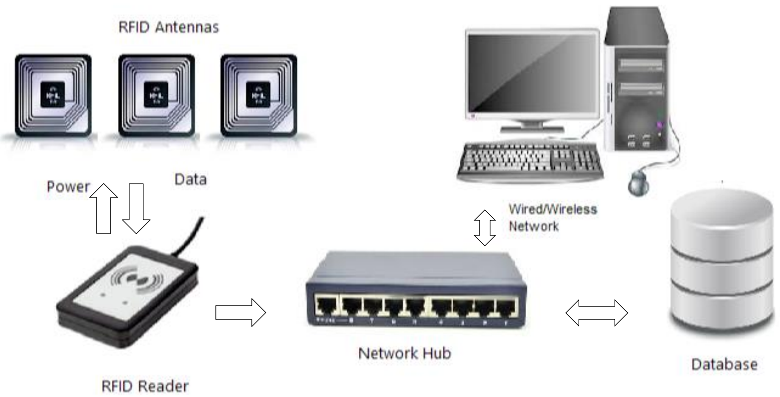



**Figure 3.3:** Schematic of RFID

RFID is a widely used technology in indoor positioning systems. There are many existing studies on the subject. RFID technology has some advantages to indoor positioning. They work in all kinds of environments, the presence of inexpensive small and cheaper passive carriers, the receiver and transmitter need not have to see each other directly. The disadvantages of using RFID are as follows; Passive carriers are less sensitive than activators, RFID readers are expensive.

The use of RFID in locating is applied in two different ways. Carrier is stationary, reader is mobile systems. The designated point carriers are placed in the building. Readers are located on the moving person or objects. In these systems, the location of the person or object can be found by making use of the known positions of the carriers which are in the reading fields of the reader [15].

The sensitivity of this system depends on the carrier frequency used. Considering the large constructions, the number of the carriers that are received is increasing too much. It is increasing in terms of workload and cost. In the other system, readers are fixed, and carrier is mobile. In these systems, the carriers are on the object or persons that are being followed. The readers are placed in predetermined locations. The RSSI values from the RFID carrier are used to estimate the location. The distance between the carriage and the reader is important and distance is inversely proportional to signal strength communication breaks at a certain level. In these systems, prediction is made by triangulation and trilateration methods which will be explained in the future.

### 3.1.3 UWB

UWB is a short-range RF based localization technology which has a high bandwidth and has more sensitivity that other RF-based technologies like Wi-Fi and RFID can not reach. It is one of the fixed indoor positioning system which is based on sensing short pulses. UWB signals are suitable for indoor positioning applications because they can pass through walls, windows and other obstructions but due to expensive installation, UWB is not suitable for large scale implementations [23].

There are many studies using UWB. In these studies, accuracy of 4-20 cm is reached using TOA, TDOA, AOA and fingerprinting techniques to calculate the distance between the reference points and the target. RSS is generally better suited for systems that use narrowband. UBISENSE 2011 is an UWB based automation solution for indoor localization which uses tags, fixed infrastructure and location management platform. There is an array of antenna and system uses AOA to determine the position [24].

UWB systems simultaneously use multiple bands of frequencies for signal transmitting. In contrast to narrowband, UWB waves cover large frequency band. Federal Communication Commission (FCC) in USA limited the unlicensed UWB communications to avoid interference with the existing radio services. FCC limited bandwidth frequency to 3.16 GHz to 10.6 GHz and allows maximum -41 dBm power spectral density for commercial UWB devices [25].

### 3.1.4 Bluetooth

Bluetooth is the name of short-range radio frequency (RF) technology that eliminates the cable connection. Bluetooth was developed by Ericsson in 1994 to establish wireless connection and communication among mobile phones and other mobile devices even if out of LOS. The distance, that Bluetooth-enabled devices capable of transmitting data up to 24 MBPS is effective about 10 to 100 meters. It provides users with full control over their smart home products, right from light bulbs to smart locks, from anywhere in their home and daily life.

Over the years, different versions of Bluetooth technology have been developed. It started with the version 1.0 which had several problems. Later in 2002 v1.1 published and Signal Strength Indicator and non-encrypted channels were added to this version. V1.2 increased the speed. In 2004 Bluetooth v2.0 released and used Enhanced Data Rate (EDR) to improve data transfer rate. In 2007 v2.1 released, with this version brought secure simple pairing (SSP) which is more efficient and secure for data transmitting. In 2009 Bluetooth v3.0 released with improved transfer speeds of up to 24 Mbit/s. In 2010, new version Bluetooth 4.0 was released which is called Bluetooth Low Energy or Bluetooth Smart. This system has ultra-low power consumption, new software stacks and changed radio frequency properties [8]. One year after, v4.1 was released. It had an update for software. In 2014, v4.2 came out and this version is more useful for IoT. Also, a new version released which is called Bluetooth 5.0 with up to 4x the range, 2x the speed and 8x the broadcasting message capacity in 2016. The enhancements of Bluetooth 5.0 focus on increasing functionality for the Internet of Things (IoT). Bluetooth Low Energy technology will be explained in more detail than other technologies, since the system will be developed by using Bluetooth Smart technology in this master thesis.

Bluetooth Low Energy uses the same antenna and frequency as classic Bluetooth. This system is also called Bluetooth Smart. This technology is being used in smart homes, health and medical devices, PC and consumer electronics, automotive, retail and location-based services. Estimates show that the size of the Bluetooth chipset market will grow more than 19 billion in 2019 [26]. Bluetooth Smart device is shown in Figure 3.4.

The most important feature of Bluetooth Smart device is that it can operate for very long time with a simple coin battery, so power consumption is reduced to between 50-99% of the classic Bluetooth power consumption [27].

There have to be two device nodes, slave and master, acting as receiver and transmitter. BLE 4.0 technology is not compatible with classic Bluetooth stack, that's why the new devices support both of them. The new standard was introduced to send low amount of data like sensor values or control commands [12].

**Figure 3.4:** Bluetooth Smart device

In Bluetooth Smart, there is no need to do pairing to exchange the data. Advertisement channels send data in broadcasting mode without pairing. This new type of device also called Beacon. In the signal, there exist Received Signal Strength Indicator, link quality parameter, transmitted power level parameter and inquiry response rate information. Shortly received signal strength indicator is RSSI and varies between -127 dBm and 20 dBm. If the value increases, that means the signal strength increases, and become nearer [8]. If the device is in 2 meters away this means it is very close. If the device is 2-5 meters away from the AP, it means it is near and if 5-10 meters away from AP, it means it is far.

Although Bluetooth Smart is not an active connection, an established connection can take RSSI value from passively receiving advertisements. The most important advantage of Bluetooth Smart is its availability in all digital devices.

These features make Bluetooth technology advantageous for locating position indoors. Algorithms and the techniques for obtaining distance from beacon signals will be handled in the following sections.

### 3.2 Position Estimation Methods

There are some challenges due to indoor environment like accuracy, responsiveness, calibration effort, adaptive and operational constraints [15]. Special algorithms and methods have been developed for these reasons. Figure 3.5 shows the methods which are used for indoor positioning. Some of these methods are described in the sub sections of this part.

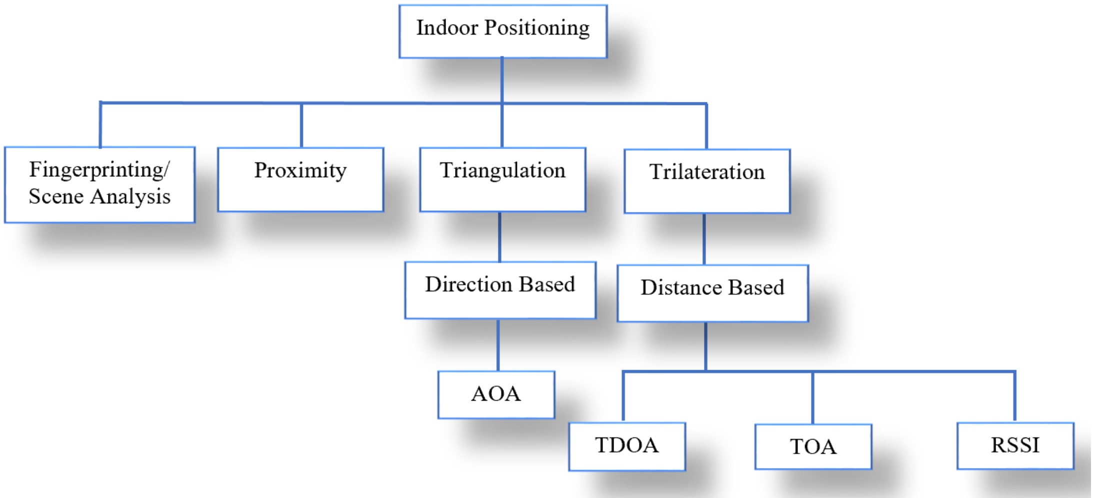



**Figure 3.5:** Positioning techniques

#### 3.2.1 Triangulation

Triangulation method makes positioning by measuring the angles of the arrived signals and uses geometric properties of triangles to compute object locations. The distance is determined by the angles of the signals that are emitted from each device [28]. This technique is based on Angle of Arrivals (AOA) of wireless signals and at least two reference points required. The device can calculate its own position with the angle of the obtained signals which are emitted from transmitters. Schema of the triangulation formula can be seen in Figure 3.6.

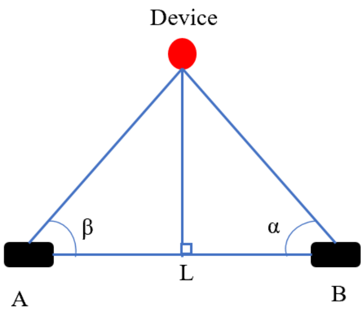



**Figure 3.6:** Triangulation formulation

For two reference points, there will be two angles which can be called α and β. The distance is determined with the following formulation;

$$D = L\frac{sin(\alpha).sin(\beta)}{sin(\alpha + \beta)} \tag{3.1}$$

where L is the distance between both receivers.

A person or an object carries the device and reference points A and B can be seen from the position of the device. If the positions of A and B are known, the position of the device can also be found by constructing a triangle. Triangulation technique can be used with Wi-Fi, BLE, UWB and LTE signals for indoor position estimation [29]. Another triangle method involves three reference points which have specific positions. By the help of the angles of arriving signals, the mobile node can determine its own position. A schema for triangulation with three access points is shown in Figure 3.7.

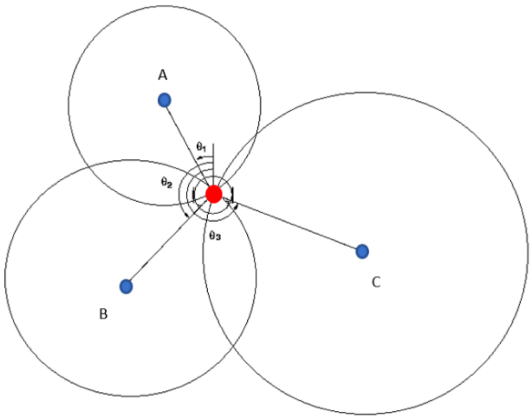



**Figure 3.7:** Triangulation with three reference points

### 3.2.2 Trilateration

Trilateration is used to determine the position by using distances to known reference points in surveying, navigation and GPS. Trilateration requires the distance between the receiver and the transmitter for measuring and uses three reference points which are known positions. If we compare trilateration and triangulation, triangulation measures the angle of the received wireless signals, trilateration measures the distances to the reference points. Provided that the receiver and transmitter are synchronized, received signal strength indicator (RSSI), the time of arrival (ToA), or the time of flight (ToF) of the signal, are calculated for each reference point in order to determine the radius. For three reference points, there will be three spheres and the device's position is then determined by observing the intersection of the three radii [29]. The Figure 3.8 illustrates the Trilateration Technique.

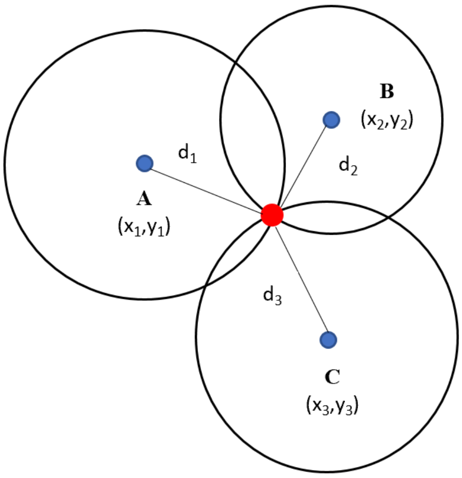



**Figure 3.8:** Position estimation with trilateration

The intersection of the surfaces of three spheres is found by formulating the equations for the three sphere surfaces and then solving the three equations for the three reference points. This intersection point is the possible location of the transmitter. For trilateration calculations, exact location of the reference points and estimated distances from each reference points to the device should be known.

Lets say $x_b$, $y_b$, $z_b$ are the beacon coordinates. The distances can be calculated as follows;

$$r_i^2 = (x_i - x_b)^2 + (y_i - y_b)^2 + (z_i - z_b)^2 \tag{3.2}$$

$$\begin{aligned} r_1^2 &= (x_1 - x_b)^2 + (y_1 - y_b)^2 + (z_1 - z_b)^2 \\ r_2^2 &= (x_2 - x_b)^2 + (y_2 - y_b)^2 + (z_2 - z_b)^2 \\ r_3^2 &= (x_3 - x_b)^2 + (y_3 - y_b)^2 + (z_3 - z_b)^2 \end{aligned} \tag{3.3}$$

If all spheres are on one plane, these equations will be simplified as follows for three circles;

$$\begin{aligned} r_1^2 &= (x_1 - x_b)^2 + (y_1 - y_b)^2 \\ r_2^2 &= (x_2 - x_b)^2 + (y_2 - y_b)^2 \\ r_3^2 &= (x_3 - x_b)^2 + (y_3 - y_b)^2 \end{aligned} \tag{3.4}$$

These equations reduce to linear set of simultaneous equations which can be solved by using the following matrices.

$$(x_1 - x_b)^2 - (x_3 - x_b)^2 + (y_1 - y_b)^2 - (y_3 - y_b)^2 = {r_1}^2 - {r_3}^2$$
$$(x_2 - x_b)^2 - (x_3 - x_b)^2 + (y_2 - y_b)^2 - (y_3 - y_b)^2 = {r_2}^2 - {r_3}^2 \qquad (3.5)$$

$$2(x_3 - x_1)x_b + 2(y_3 - y_1)y_b = ({r_1}^2 - {r_3}^2) - ({x_1}^2 - {x_3}^2) - ({y_1}^2 - {y_3}^2)$$
$$2(x_3 - x_2)x_b + 2(y_3 - y_2)y_b = ({r_2}^2 - {r_3}^2) - ({x_2}^2 - {x_3}^2) - ({y_2}^2 - {y_3}^2) \qquad (3.6)$$

$$2\begin{bmatrix} x_3 - x_1 & y_3 - y_1 \\ x_3 - x_2 & y_3 - y_2 \end{bmatrix}\begin{bmatrix} x_b \\ y_b \end{bmatrix} = \begin{bmatrix} ({r_1}^2\text{-}{r_3}^2) - ({x_1}^2\text{-}{x_3}^2) - ({y_1}^2\text{-}{y_3}^2) \\ ({r_2}^2\text{-}{r_3}^2) - ({x_2}^2\text{-}{x_3}^2) - ({y_2}^2\text{-}{y_3}^2) \end{bmatrix} \qquad (3.7)$$

Multilateration is a position estimation technique similar to trilateration with more than three reference points [28]. If there are more than three reference points, some other methods like least squares can be applied to find a more accurate intersection point.

### 3.2.3 Proximity

The proximity is a method for indoor location finding which is easy to implement, the location of the device can be found by its existence in a defined area. Proximity based algorithms provide approximate location information of the mobile device [29]. This method uses the strongest received signal strength and finds the location according to this information. The scenerio of the method is; a mobile node exists in the range of a known station then system can estimate the location from the strongest signal to the known station. When more than one antenna detects the mobile node, the mobile node is assumed to be located close to a known station with the one that receives the strongest signal. The accuracy of the technique is based on the number of anchor (base or reference) points and the signal range. Generally, the proximity systems are based on IR, Bluetooth and RFID Technologies [18]. According to the research results, this method uses RSSI and has accuracy changing from low to high. It has good coverage and can be used in LOS or NLOS environments. There is no multipath affect and this technique has low cost [16].

### 3.2.4 Fingerprinting

Radio waves can pass through all kinds of obstacles and objects, so the signal strength weakens, reflects, and loses. Therefore, it is necessary to minimize such problems in order to be reliable and consistent while positioning via RSSI. Fingerprinting or scene analysis technique uses received signals for indoor localization by comparing the RSSI measurements to overcome these problems.

There are three different approaches for fingerprinting [30];

1- Deterministic approach which represents the signal strength of the AP by a scalar value. RADAR is an example for this approach with using k-nearest neighborhood.

2-Probabilistic approach which focuses on the stored information about the signal strength distributions from APs in the radio map. Horus is an example with Bayesian network [31].

3-Machine learning approach which uses SVM, fuzzy logic and artificial neural networks for determining the user location.

Fingerprinting technique consists of two stages which are offline and online [23]. Before the offline stage, the locations of the reference points were determined on the map of the environment and the precise coordinates were recorded into a database. These recorded coordinates are used in the online stage. We can call offline stage as data acquisition phase, whereas the online stage as positioning. Offline stage is the training phase for localization. For training purposes, the area of interest is divided into grids which are generally 1mx1m, and each grid corresponds to a reference point. At this stage, for each predetermined reference point, certain numbers of RSSI samples are taken. The average of these measurements are calculated and the expected RSSI values of each reference point are determined. The signal strength of the reference points are recorded into a database. This is radio map of the targeted area. Online stage is determining the location of the mobile device with the observed signal strength and the radio map of the targeted area. At this stage, the instantaneous position of the device is calculated. During each location query, the signals from all APs that the mobile device can capture at that moment are compared with the average AP signals in the signal map. Thus, a list of reference points closest to the device is determined. The number of reference points and measurements are also important for a quality radio map. After this step the position of the device can be calculated by using the obtained nearest reference points with different methods like k-Nearest Neighbor algorithm or Markov Localization [32].

Another application was made in a school. The environment was equipped with beacons and portable devices. Fingerprinting is used with RSSI of BLE technology. The template matching is performed with Sum of Squared Difference algorithm for estimation [23].

Estimation of distance over the signal strength with RSSI is relied on ideal indoor environments. Fingerprinting has a high performance with medium accuracy. This technique is complex and expensive. Offline stage is time consuming and constructing the location map requires significant effort [28].

The most popular algorithms are shown below in Table 3.1.

**Table 3.1:** Fingerprinting algorithms.

| Algorithm | Information | Reference |
|---|---|---|
| K-Nearest Neighbor (k-NN) | Classification algorithm used for pattern recognition with storing all existing cases and classifies new cases according to a similarity measure. Euclidean distance is used for calculating the distance between neighbors. | [33] |
| Artificial Neural Networks (ANN) | It is an information processing paradigm inspired by the structure of the biological nervous system. This model has learning capability and is able to achieve high accuracy for indoor positioning with less computation time. | [34] |
| Support Vector Machine (SVM) | It is an algorithm used for classification. Inputs are classified according to their properties. These two groups are shown on a plane. Two boundary lines are drawn parallel to each other and these lines are drawn close to each other. A common boundary line is determined. | [35] |
| K-Means Algorithm | K-means is the algorithm which is developed to group a certain number of clusters over a given set of data. A set of n data objects is divided into k sets of data given as input parameters. The algorithm aims to find the center by reducing the distance between the clustering center and the members of the same cluster. | [36] |

### 3.3 Signal Measurement Methods

In the literature, there are various signal measurement methods. In this thesis we focus on four most popular methods. These are time-of-arrival (TOA), received signal strength (RSS), time-difference-of-arrival (TDOA) and angle-of-arrival (AOA). All methods have some advantages and disadvantages over others. From the point of accuracy, TOA and TDOA methods are the best but they require precise synchronization of measurement units. AOA method is complex, and cost of transceivers and antenna modules are higher than other methods. So, this method is not widely used. Among others, RSSI is the most common ranging method. The advantage of this method is the mobile devices can receive signal strength measurements during standard operation of the existing Wi-Fi networks. This method is low cost and there is no need for special hardware. [37].

#### 3.3.1 Received signal strength indicator (RSSI)

The RSSI is defined in IEEE802.11 standard, which is the power level measurement between the transmitter and the receiver presented by dBm unit. The RSSI can be decreased exponentially according to the increase of distance [38]. For example, a RSSI value of - 40 dBm is more valuable than a value of – 60 dBm. It means that there is a good connection with the device which has – 40 dBm RSSI value. That means this device is close to us. If the receiving node knows the output power of the incoming signal, the taken way can be estimated by looking at the power of the receiving signal [39].

Radio propagation model is divided into three categories;

First one is free space propagation model which describes loss of signal strength over distance and requires open environment. Formula is;

$$P_r(d) = \frac{P_t . G_t . G_r . \lambda^2}{(4\pi d)^2 L} \tag{3.8}$$

Where $P_r$ (d) is the received power, $P_t$ is the transmitter power, $G_r$ is the receiver antenna gain and $G_t$ is the transmitter antenna gain. Second model is two-ray ground reflection model which is used in the case where the transmitter and receiver at the known distances from the ground. This model accounts for multipath fading over long distances. Formula is;

$$P_r(d) = P_t . G_t . G_r . \frac{{h_t}^2 . {h_r}^2}{d^2} \quad (3.9)$$

Where $h_t$ is the transmitter antenna height and $h_r$ is the receiver antenna height.

Third model is log-distance model which is the general propagation model. This method can be used both indoor and outdoor environments. RSSI calculation formula is as follows:

$$RSSI_{dBm} = -10. n. log_{10}( d) + A \quad (3.10)$$

Where n is the path loss exponent or signal propagation constant, d is distance from sender or transmitter and Ais received signal strength in dBm at a distance of one meter. Solving Equation 3.10 for $d$ leads to the Formula in 3.11;

$$d = 10^{\frac{A-RSSI}{10.n}} \quad \text{The relation between d and RSSI} \quad (3.11)$$

Received signal strength indicator (RSSI) is presented as a standard feature in many hardware today and is preferred because of the reasons such as energy saving, small knot size and low cost. The RSSI method has been included in the literature as the most widely used positioning method that estimates the distance between two nodes [26].

### 3.3.2 Angle of arrival (AOA)

This method calculates the angles of the signals that reach one or more receivers from a given point with the receiver antennas. Two receivers are sufficient to obtain position information in a two-dimensional plane. 3 or more receivers are used at the point scale to increase the accuracy. Directional antenna or antennas are required to determine direction. Then, by taking advantage of the geometric properties, the position of the nodal point of the intersecting two lines can be estimated. AOA methods also have their own disadvantages. The AOA technique requires special antennas to measure angles, which increases the cost of AOA technology.

It is affected by multipath in enclosed areas. These effects can greatly change the angle of arrival of the signal, which significantly reduces positional accuracy [27].

### 3.3.3 Time of arrival (TOA)

Time of Arrival is the travel time of a radio signal from a transmitter to a receiver. Arrival time methods are based on high accuracy synchronization of the arrival time of the signal transmitted from a mobile device to several reference points. In the TOA method, it sends the time processed signal to the handset to several receivers. The distance between the mobile point and the receiver points is calculated with the aid of the signal transfer delay and the speed of the corresponding signal. At least three sensor nodes are required for positioning. The $4^{th}$ node will be required for time correction [40].

UWB has a good accuracy due to the high time resolution (large bandwidth). So, synchronization requirement of TOA method can be compansated by a system with UWB signaling [41].

The basic equation for TOA can be seen in Equation 3.12;

$$r = txc \tag{3.12}$$

Where c is the traveling speed of the signal, t is the time of spent in the signal travelling from transmitter to receiver and r is the distance between transmitting node to receiving node.

### 3.3.4 Time difference of arrival (TDOA)

The relative position of the transmitter can be determined by the differences in the TOA of the signal from mobile unit to multiple measurement units. TDOA is a mathematical positioning method based on passive radar methods which is used by GSM operators. It based on low energy consumption and hyperbolic equations. The distance is calculated based on the propagation time and the speed of the signal in this method. It finds out the relative location of the transmitter by the difference in time at which the signal arrives from multiple measuring units. Representative picture for TDOA can be seen below Figure 3.9.

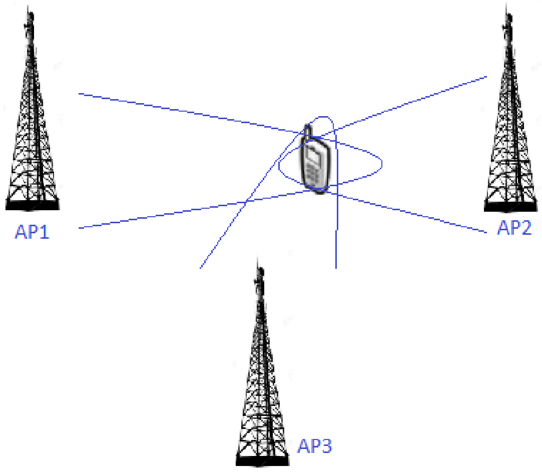



**Figure 3.9:** TDOA

Time difference of arrival uses multilateration or hyperbolic positioning to locate the transmitter. Since the synchronous receiving antennas are located in different places, the transmitter signal is reached at different times to the receiver. The first receiving antenna is regarded as the reference point. Now, the time of arrival of the same signal to other receivers is monitored synchronously by the host. The time of arrival to the other two receiving antennas and the time difference between the receivers are measured. Hyperbolic equations can be formed by using these time differences. The solution of the generated hyperbola equations is to find the position of the target point relative to the first reference point and corresponding software transforms this information to the position information [40]. This method is like TOA, but it finds the relative location of the mobile transmitter instead of absolute arrival time as in TOA. Synchronization is required as any other time-based methods for accuracy.

This method is expensive, more accurate, has less calibration requirements but needs complex infrastructure to get high performance [23].

### 3.4 Implementation Strategies

Indoor positioning systems can be implemented in two different ways. These are network-based approach in which the location calculation is made by the server and other one is the device-based approach in which the location calculation is made by mobile device [29].

### 3.4.1 Device-based positioning

The signals from transmitters are gathered from mobile device. The position calculated by a software with estimation algorithm on the mobile device or on remote server. The person or object to be tracked have to carry a smart device which can be a mobile phone or smart wearable. The environment is equipped with transmitters. Device-based positioning diagram can be seen in Figure 3.10.

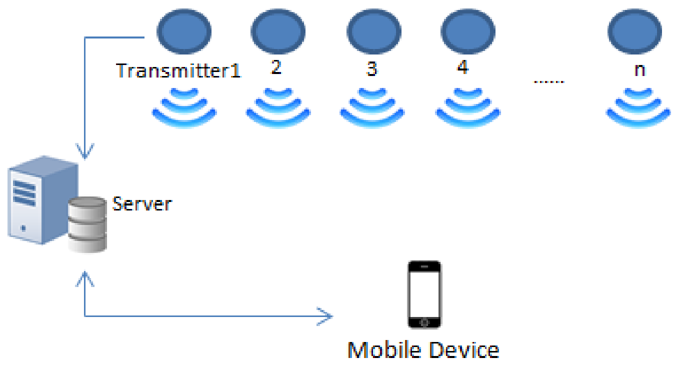



**Figure 3.10:** Device-based positioning

More precise location estimates can be done with the sensors on mobile devices together with RSSI. This method can lead to battery run-down because a continuous application runs on the device. This is a disadvantage in terms of use.

Mobile-based wireless positioning system CAPTURE which uses fingerprinting and KNN method is an example for devised-based implementation [42]. Mobile device scans the environment and determines the best three transmitters by the help of the received signal strengths. The device sends the information to the server and system calculates and compares the position with the trained data in the database.

### 3.4.2 Network-based positioning

In the network-based positioning, transmitter device is located on a person or object. The environment is equipped with access points connected to the network. The transmitter signal is received by the APs and the location is estimated by software on a server for positioning purposes. This method of application is more advantageous in terms of battery usage. However, the characteristic of the device is important. System can be seen in Figure 3.11.

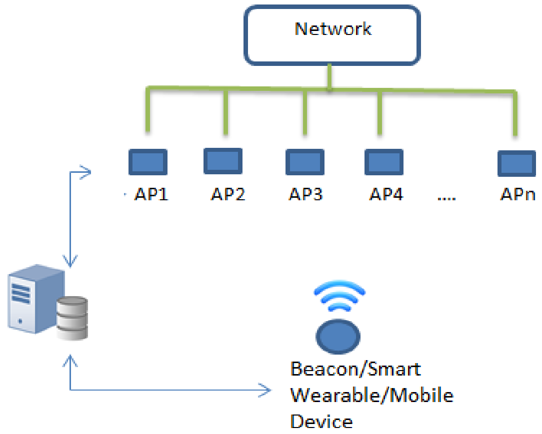



**Figure 3.11:** Network-based positioning

A system, which finds the locations of the students in campus buildings through Wi-Fi enabled devices, has been developed [43]. System collects a set of data which includes RSSI of the Wi-Fi devices and uses the multilateration algorithms with various filtering algorithms. This study is a good example for network-based implementations.

### 3.5 Commercial and Academic Applications

Various commercial and academic applications were observed in the literature survey. New solutions are being introduced continuously by adding new technologies and improving existing ones.

Some of the academic research projects and commercial products are listed in the below Table 3.2. There are also many other solutions in the market and different studies which explains them in detail [25, 28, 44].

### 3.6 Related Works

In the thesis study, position estimation is performed by trilateration and linear least squares with signals from Beacons.

**Table 3.2:** Academic and commercial localization systems.

| Name | Information | Technology | Method | Accuracy | Ref |
|---|---|---|---|---|---|
| Microsoft RADAR | RF-based user location and tracking system, research project | Wi-Fi, Mobile device | Triangulation, Fingerprinting | 2-3 m | [45] |
| MIT Cricket | Beacon-based indoor positioning | Beacon, Ultrasonic signals, Mobile devices | TDOA | 2 cm without NLOS environment | [46] |
| Active Bat | Indoor location system with ultrasound measurement | Ultrasonic Sensors | Multilateration TOF | 9 cm | [47] |
| Intel Place Lab | Low-cost and easy positioning system for both indoor and outdoor | Mobile device, Beacon, Wi-Fi, GSM cell phone towers, Existing Bluetooth devices | Beacon database, GSM tower locations | Depends on the density 802.11 beacon only 20 m, GSM beacons alone 100-200m, 802.11+GSM 22.6m-42.4m | [48] |
| Ekahau | Wi-Fi based real time location finding system | Wi-Fi Tags, Access Points, RFID | Trilateration, N-N Algorithm | 1.5-3 m | [49] |
| LANDMARC | Location identification based on Dynamic Active RFID | RF Signals, Active RFID | k-Nearest Neighbor | 1-2 m | [50] |
| Skyhook Wireless Inc. | Hybrid Localization System with fingerprinting | WLAN, cell tower and GNSS positioning | RSSI | 10 m | [25] |

**Table 3.2 (continue):** Academic and commercial localization systems.

| Name | Information | Technology | Method | Accuracy | Ref |
|---|---|---|---|---|---|
| Ubisense | Real-time location system with UWB technology | Ubisense sensors, Ubisense tag, Ubisense location software | Hybrid combination of UWB ToA and TDoA measurements | System achieved 26.736 cm accuracy | [51] |
| Indoo.rs | IPS for Enterprises | WiFi, BLE, Sensors, SLAM Engine | Trilateration/ Triangulation | 2 m | [52] |
| Indoor Atlas | Geomatic Technology IPS | Compass of smart device, WiFi, magnetic sensors | Fingerprinting | 1-2 m | [53] |
| Philips Lighting | LED based positioning System | Philips lumniaries with Philips VLC, smart phone | Fingerprinting, camera-based approaches | 5-30 cm in case of LOS between smart phone camera and light source | [44] |

Using Bluetooth for positioning is popular because of the availability in mobile devices and the easy installation of the system. Recently there are Wi-Fi access points ready on the premises and BLE beacons are placed on the floors of the buildings. Both technologies are being used together to increase accuracy [10].

The RF Based indoor positioning technique with BLE is described in an academic study. Two-dimensional x and y coordinates are used and third coordinate is neglected. Four different positioning methods, which are trilateration, iterative trilateration, a particle filter and a fingerprinting, have been tested using Bluetooth Smart technology [8].

In another thesis, trilateration is used with Bluetooth RSSI values without connection establishment. Four mobile phones which have Android operating systems are positioned as a transmitter to the corners in the rectangular test area. The target is also a mobile device with the Android operating system. Three different methods, which are least squares estimation, trilateration and centroid positioning, were used to estimate position. As a result, 0.6 meter accuracy has been achieved [54].

There is an other study which finds mobile robot location with Bluetooth in indoor environment [55]. Three beacons were located at fix coordinates in a 6m x 8m floor with furniture. Iterative trilateration and pseudo-inverse trilateration were compared to calculate autonomous robot position in the interior. According to this study iterative trilateration method is more accurate than pseudo-inverse trilateration method. It was observed that the error rate was lowered by using particle filter.

Another study in the literature used a model similar to our solution [56]. BLE devices were being used as transmitters. Channel diversity, Kalman filtering and a weighted trilateration technique were used for improving the sensitivity of the IPS System.

# 4. BLE BASED INDOOR POSITIONING

In this part of the study, our own system will be described in detail. System architecture, test bed setup, data acquisition, algorithm implementations and graphical layout will be provided.

There are some parameters that must be considered when installing the system. These are accuracy, coverage area, and number of users, scalability, cost and robustness. In the study, a scenario that is not dependent on smart devices is considered. The study includes an object or person tracking who or which does not have an ongoing smart device.

Our system architecture can be divided into three parts: APs setup, data acquisition and data analysis. The general structure of our system is illustrated in Figure 4.1.

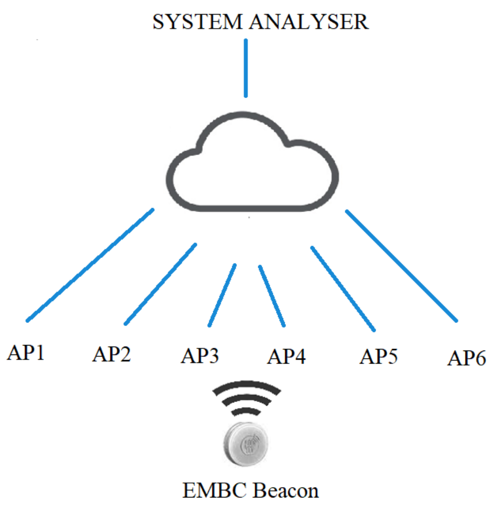


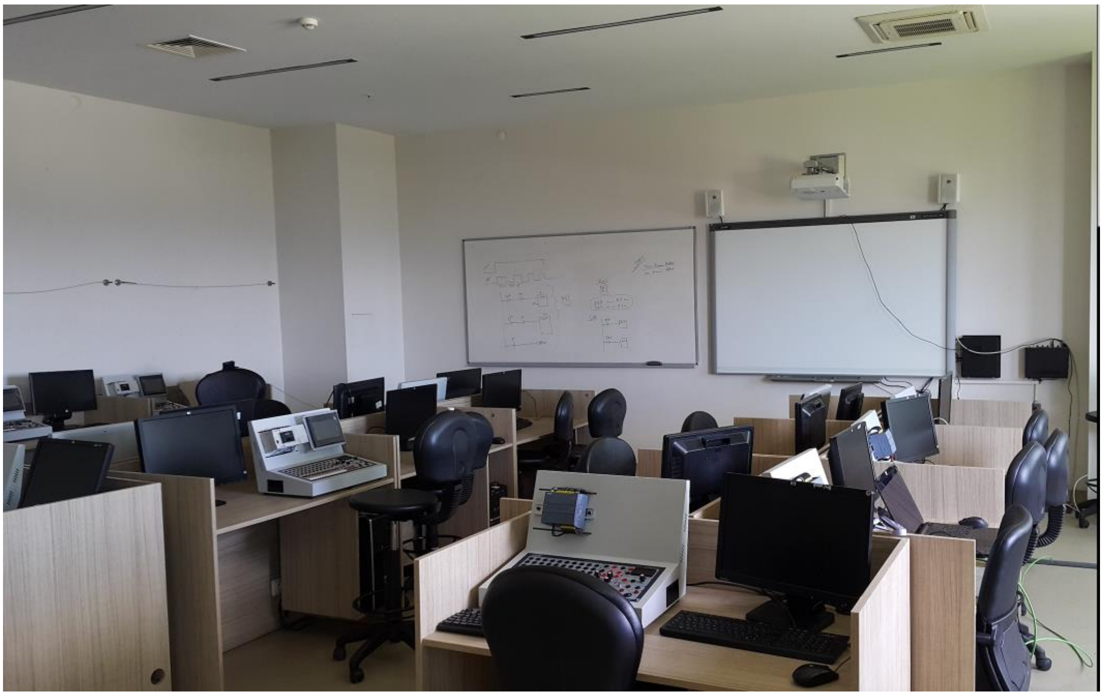

**Figure 4.1:** System structure

In the first phase; APs were placed in predetermined locations and they were prepared for data acqusition. In the second phase, APs collected the beacon data and send to the server. In the third phase, the software on the server utilized the signal data in a series of calculations to find the position based on the beacon RSSI.

## 4.1 Test Environment and Setup

The evaluation is performed in a PLC Lab in the university. A 13.1 x 6.5 m rectangular area was with six APs which are located 2 meter above from the floor, on the building carrier walls. The environment was furnished and two pictures of the test area is presented in Figure 4.2(a) and 4.2(b).

**(a)** Right Side



**(b)** Left Side

**Figure 4.2:** Test area

The overview of the test area plan is illustrated in Figure 4.3.

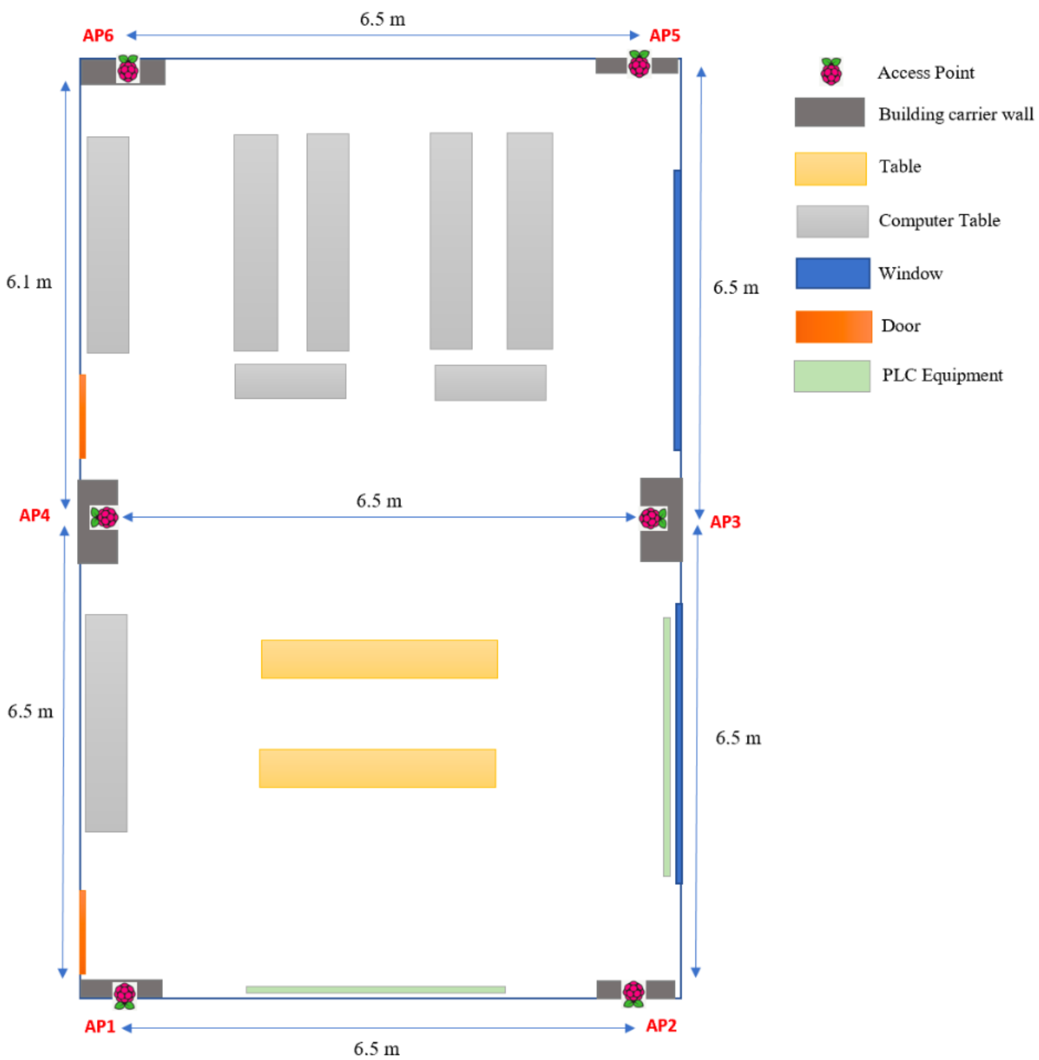



**Figure 4.3:** Plan of the test area

The Wi-Fi network were active and there were many other Bluetooth signals in the environment. It was a real life scenario with noise and obstacles. Test environment consists of two different components; software and hardware.

### 4.1.1 Hardware

Beacons are basically allow mobile devices to discover where they are located in a very small area. They can operate continuously up to 3 years with a normal coin battery. Due to the fact that, this is the biggest difference with traditional Bluetooth. Figure 4.4 presents the picture of the EMBC01 beacon device. BLE technology is designed for small data transfers in short periods. Since they have one-way data transmission, they are highly secure.

There are different types of beacons like iBeacon, AltBeacon and URIBeacon in the market. They all have their own standards and advantages. iBeacon is the first BLE Smart Beacon technology product developed by Apple. It has a closed standard. AltBeacon is an open, cost free beacon specification which is the format of the broadcasting message.

Within the scope of the project, transmitters are BLE beacons, which are constantly broadcasting. EMBC01 BLE Proximity Beacon product of EM Microelectronics was preferred. Each beacon has a globally unique code that is periodically broadcast through Bluetooth signals. Beacon ID packet of EMBC01 advertisement includes UUID, Major ID, Minor ID and Tx power data which are common Beacon standards.

**Figure 4.4:** EMBC01 proximity beacon

EMBC01 has three power modes;

Short Range: 15m LOS, 100ms beacon interval and 1.5 months of battery life

Medium Range: 30m LOS, 500ms beacon interval and 7.5 months of battery life

Long Range: 75m LOS, 1 second beacon interval and 12.5 months of battery life

In our system we used medium range power mode which transmits 2 beacon signals at each second. It is easy to change the mode with a button on the Beacon. In the system, Beacons were used as transmitter.

Raspberry Pi is a small single board computer with Raspbian operating system installed. To receive the BLE signals AP's must have Bluetooth interface. Raspberry Pi3 in Figure 4.5 has built-in Bluetooth 4.1 and Wi-Fi, so extra equipment like dongle was not needed. HCI is host controller interface comes ready with Raspberry Pi3.

**Figure 4.5:** Picture of Raspberry Pi3

Bluez library was installed for listening Bluetooth from code block. Suds library was installed for web service operations. 6 Raspberry Pi3 were used as access points in the test environment.

### 4.1.2 Software

In the system we have three different softwares. The first one is open source Domoticz home automation code installed from GitHub and was used with some modifications for our system. The software receives Bluetooth signals in the background and communicates with server via web service over the internet. The AP code, Beacon Id, RSSI value and date/time information are serialized in JSON format. Codes added for serializing the data and calling web service in Python software language. The flow chart of this part of software phase can be seen in Figure 4.6.

The second sofware is a web service which takes the necessary information from access points, filters and sends to the server. Service takes the AP code, Beacon Id, RSSI value and date/time information as a parameter and deserialize the JSON and records the data. Web service flowchart is shown in Figure 4.7.

RSSI Analyser sofware consists of three stages. The first stage is to calculate the calibration values of the APs. Calibration phase will be explained in detail in Section 4.2.1 . A screenshot of the software can be seen in Figure 4.8.

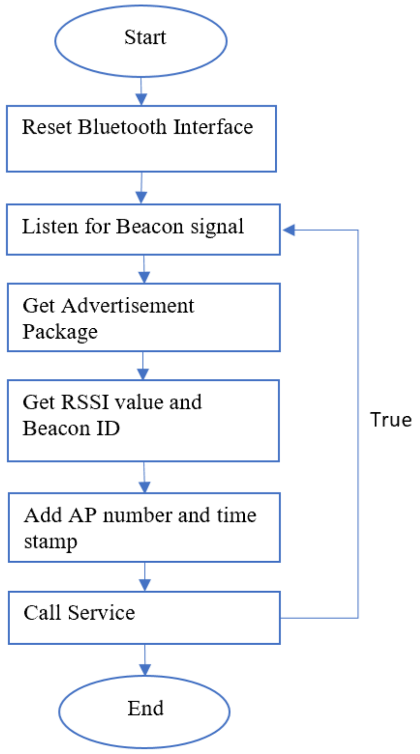



**Figure 4.6:** Receiver software flowchart

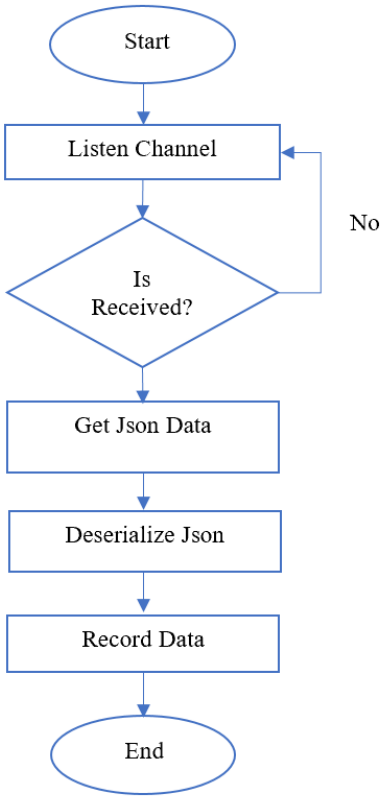



**Figure 4.7:** Service flowchart

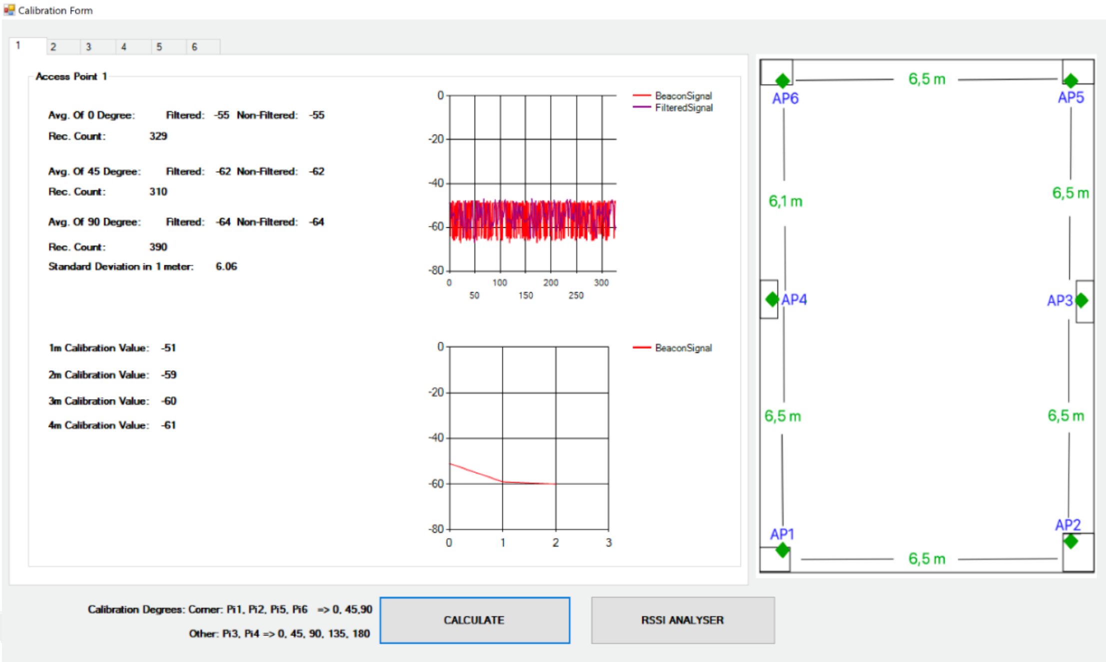



**Figure 4.8:** Calibration interface

The second stage is estimating the distances between the target and APs. In this stage, the software finds the distance value by the Formula given in 3.11 with the calculated calibration value A and path loss for each access point.

The estimated distances from RSSI values are represented as circles around the access points which are used by positioning algorithms. The calculation is presented in Table 4.1.

**Table 4.1:** Algorithm of distance calculation from RSSI.

**Algorithm: Distance Calculation from RSSI**

**CALIBRATION**
**Input:** $n_1, n_2, n_3, n_4, n_5, n_6 \leftarrow$ path loss exponents
$A_1, A_2, A_3, A_4, A_5, A_6 \leftarrow$ one-meter calibration values
**Output:** $r_1, r_2, r_3, r_4, r_5, r_6 \leftarrow$ radius values of APs

**begin**
**for** i←1 **to** 6 **do**
*RSSIList* ← read values of $AP_i$ Data
*FilteredList* ← filter RSSIList
$RSSI_i$ ← average of FilteredList
*Using Formula:* $r_i = 10^{\frac{A_i - RSSI_i}{10 * n_i}}$ Calculate radius
**end for**
**end**

The third is calculating the positions of the target. In this stage, the estimated distance of all AP's from the previous stage and the exact coordinates of AP's are being used in trilateration, linear least squares and Newton Raphson algorithms. For evaluation of the results, the exact location of the beacon and the calculated position were compared with distance formula. Figure 4.10 shows the analyser flowchart.

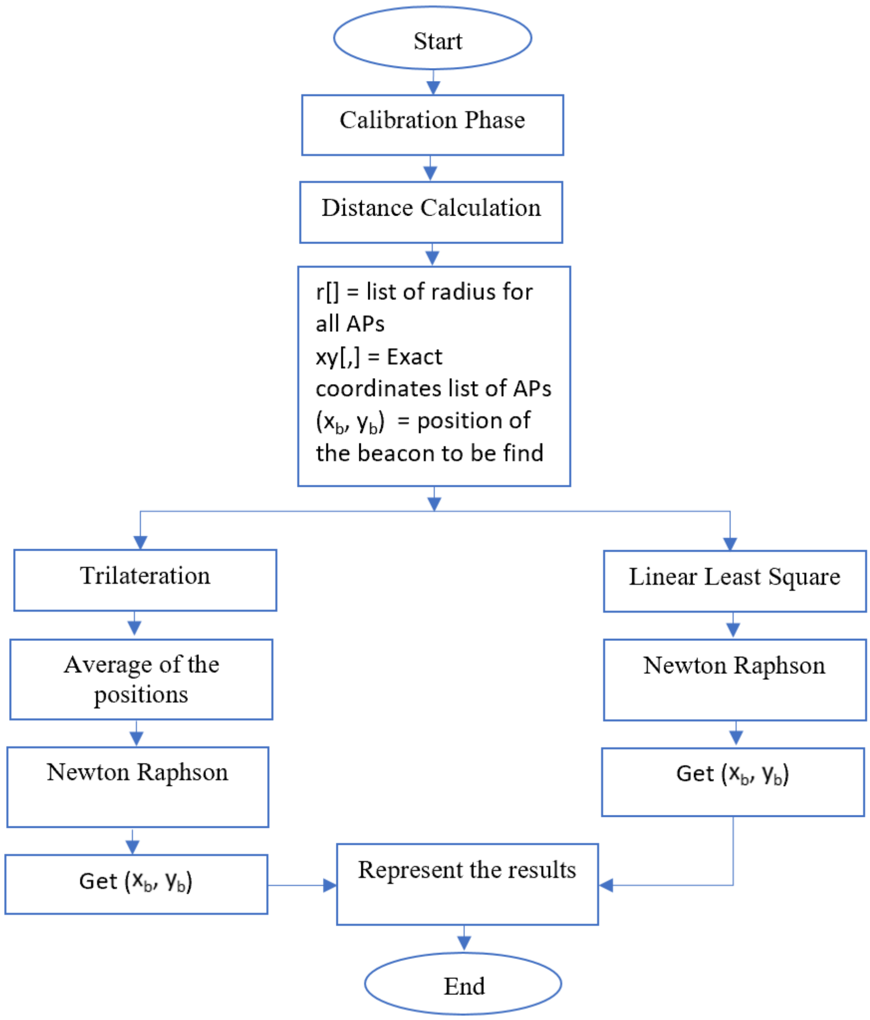



**Figure 4.9:** Analyser software flowchart

C # programming language in Visual Studio IDE was used for RSSI Analyser software. Analyser interface is shown in Figure 4.11.

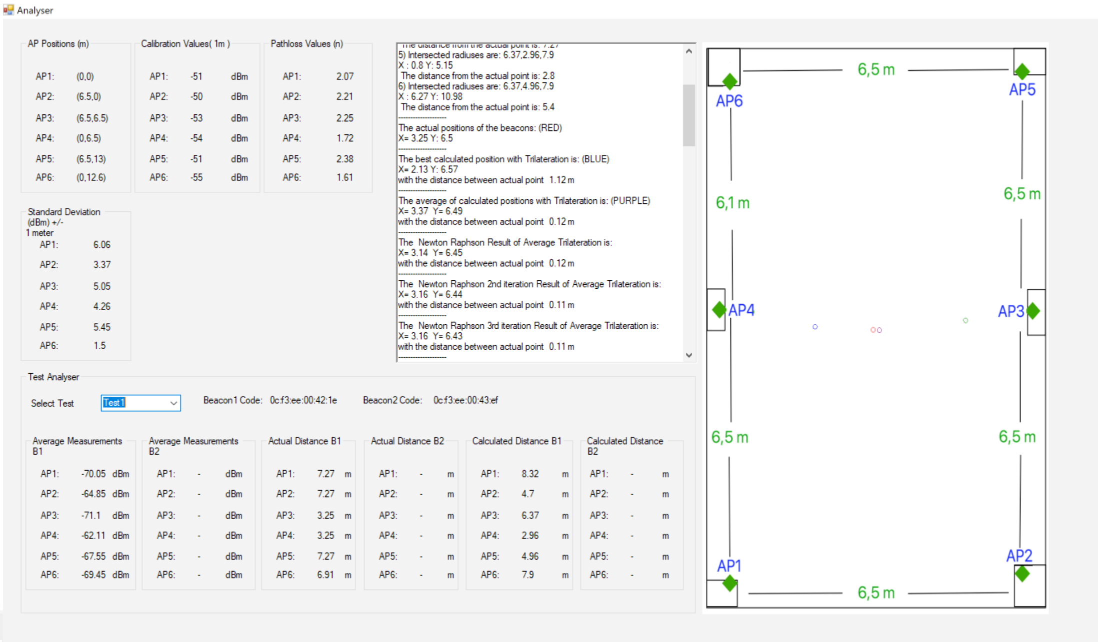



**Figure 4.10:** Analyser interface

## 4.2 Data Acquisition and Analysis

The data collection and analysis phase of the system started with a calibration process. After the calibration, tests were carried out and location estimation studies with the algorithms were conducted.

### 4.2.1 Calibration effort

Calibration is the most important phase in indoor positioning studies. Indoor environment is complex due to the obstacles like windows, walls, furnitures, metal objects and moving objects. The system needs to be calibrated according to the method. In our system, we used 2 dimensional trilateration method. The test conditions must be equal for all access points. All APs are fixed to the building carrier walls at a height of 2 meters from the ground. All access points have the same operating system, are the same brand and have the same software installed. The same beacon with 2 signals transmission period at each second was used.

The flowchart of the calibration phase represented in Figure 4.12.

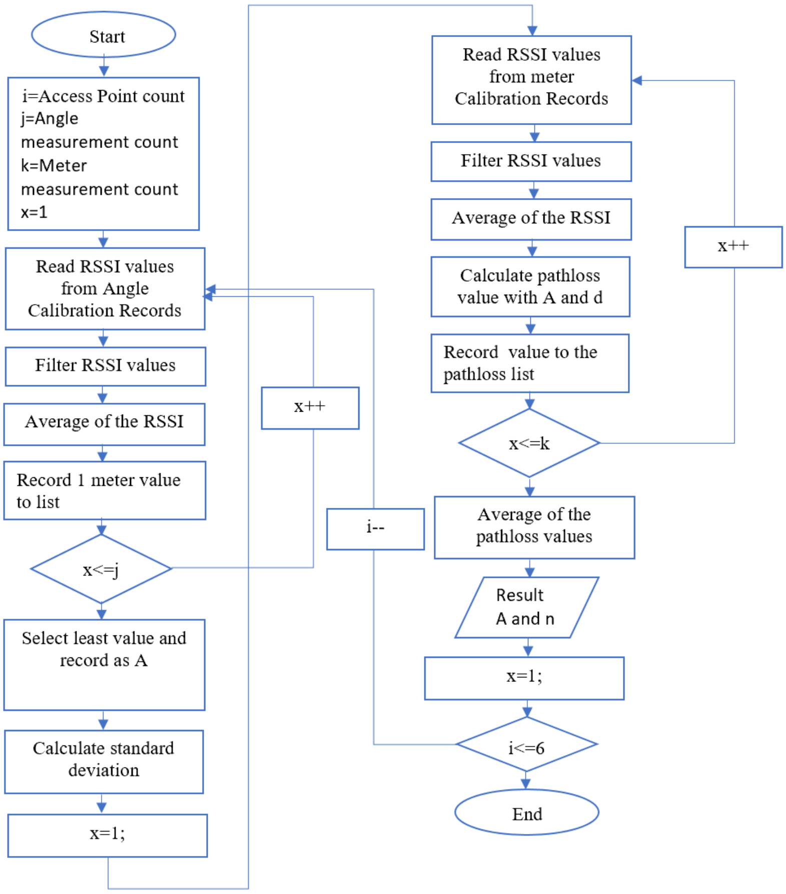



**Figure 4.11:** Flowchart of calibration phase

During the calibration process, the transmitter is positioned directly in the line of sight. To investigate the angle effect on RSSI, the data was collected from the side facing to the test area at each 45 degrees for 3 minutes. The change is seen in Figure 4.13.

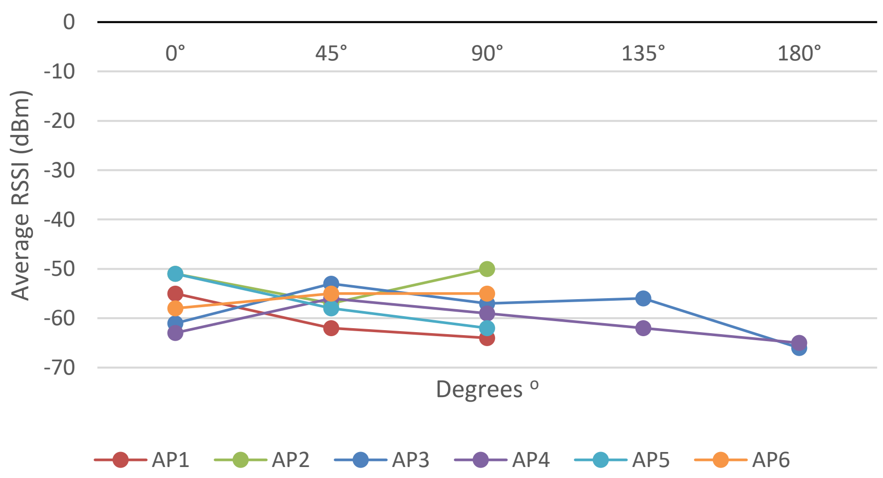



**Figure 4.12:** Average RSSI vs angle chart

The minimum value of the measurements per AP was chosen as 1meter calibration value, which is indicated by A in the formula. The collected RSSI values were filtered by the low pass filter and averaged with the Formula 4.1. A visual representation of the data can be seen in Figure 4.14.

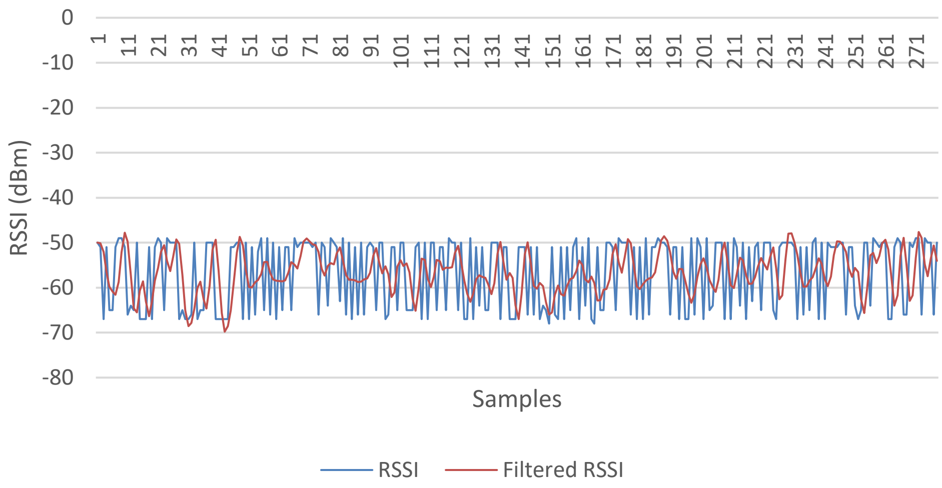



**Figure 4.13:** Low pass filter

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \quad (4.1)$$

In the formula, $\bar{x}$ denotes the mean value, $x_i$ is the $i^{th}$ value of the data set and $n$ indicates the number of values in the data set.

The other measurement was performed on a meter basis to find the n value. The measurements of up to 4 meters per access point and the values obtained in these measurements are shown in the Table 4.2. These values are used in the path loss calculation.

**Table 4.2:** RSSI (dBm) measurements versus distance.

| Distance(m) | AP1 | AP2 | AP3 | AP4 | AP5 | AP6 |
|---|---|---|---|---|---|---|
| 1 | -51 | -50 | -53 | -54 | -51 | -55 |
| 2 | -59 | -56 | -60 | -60 | -59 | -59 |
| 3 | -60 | -61 | -63 | -60 | -62 | -63 |
| 4 | -61 | -64 | -67 | -63 | -64 | -66 |

The standard deviation was calculated with the Equation 4.2 below:

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \qquad (4.2)$$

In the Equation 4.2, $\sigma$ represents the standard deviation, $n$ is number of data points, $\bar{x}$ denotes the mean of $x_i$ and $x_i$ indicates i$^{th}$ value of the data.

The following Table 4.3 shows the average path loss values of each AP.

**Table 4.3:** Path loss exponents and standard deviations of the APs.

| Access Point | AP1 | AP2 | AP3 | AP4 | AP5 | AP6 |
|---|---|---|---|---|---|---|
| **Path Loss Exponent** | 2.07 | 2.21 | 2.25 | 1.72 | 2.38 | 1.61 |
| **Standard Deviation in Signal** | 4.573474 | 6.130525 | 5.909033 | 3.774917 | 5.715476 | 4.787136 |

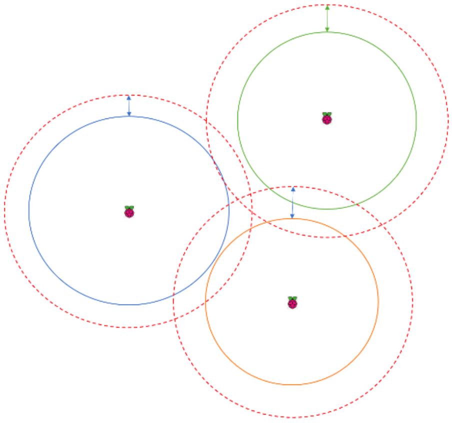
### 4.2.2 Methods

In this thesis, trilateration method by taking the average of intersections and linear least squares method were used for position estimation. Then Newton Raphson method was applied for optimization.

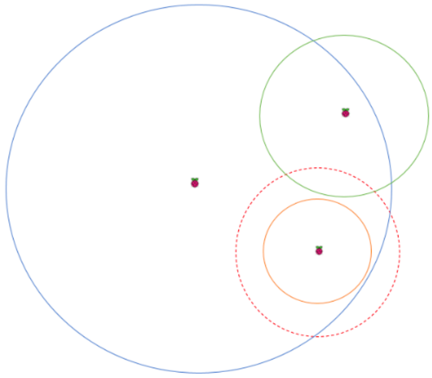
#### 4.2.2.1 Trilateration

The trilateration method and its calculations are described in section 3.2.2. Three known reference points with the known coordinates are needed for this method. These reference points are considerd to be the center of the circles and the calculated distances of the target device are the radius values of the circles. The position of the target device is obtained by finding the common solution points of the three drawn circle equations. Since the unknown position of the target, the radius values for trilateration were calculated using the Formula in 3.11. The calculated r values and the exact location coordinates of the AP's were used in the Formula 3.7 for position estimation.

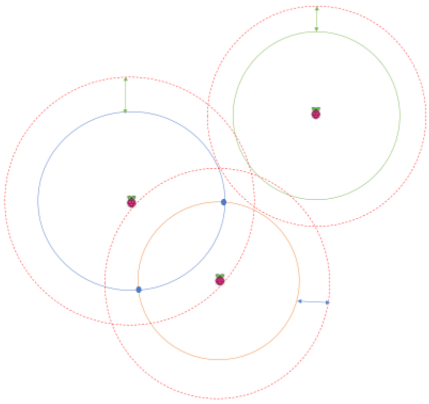
At the beginning of the study, only 3 APs were placed in the environment. The calculations showed that circle diameters vary according to the signal strength. There were exception cases where three circle intersection was not obtained. The exception cases are; circles do not intersections, one circle covers the other and two circle intersection cases. In those cases; the standard deviations which were calculated in the calibration phase with Equation 4.2 are added to the radius values for each AP. Such cases can be seen in Figures 4.14(a), 4.14(b) and 4.14(c) respectively.



**(a)** No intersection



**(b)** One circle covers another



**(c)** Two circle intersection

**Figure 4.14:** Exception cases for trilateration

In the case where the intersection area is large, the midpoint of the area can be calculated by taking the mean of the intersected points to reduce the error. Using three APs were insufficient to find a consistent solution, so three more access points added to test environment. The estimation of the position was done by taking the average of the intersection points. The algorithm of the method that we used can be seen in the following Table 4.4.

**Table 4.4:** Trilateration algorithm.

```
Algorithm: Trilateration

Input: RSSI List
        x_i, y_i for i=1 to 6 ← coordinates of APs
Output: (x_b, y_b) ← estimated coordinate of Beacon

begin
  for i=1 to 6 do← radius of APs
      Calculate r_i by Equation 3.11
  end for
  for i=1 to 6 do
      for j=i+1 to 6 do
          for k=j+1 to 6 do
              CheckIntersection (x_i, y_i; x_j, y_j; x_k, y_k; r_i, r_j, r_k)
            If three circles intersect then
              Calculate trilateration by Equation 3.7
              Add to PositionList
            end if
          end for
      end for
  end for
  (x_b, y_b) ←Calculate average of PositionList
  return (x_b, y_b)
end
```

#### 4.2.2.2 Linear Least Squares estimation

Linear Least Squares is a literation method, in which we can estimate the location of the target by linearizing the problem by a constraint with the estimated distances and the coordinates of APs. This is less complicated according to NLS. The location of the target can be found by the Formula in 4.3.

$$A\vec{x} = \vec{b} \tag{4.3}$$

The difference between the coordinates of access points and the selected linearizing AP coordinates composes matrix A.

$$A = \begin{bmatrix} x_2 - x_1 & y_2 - y_1 \\ x_3 - x_1 & y_3 - y_1 \\ \vdots & \vdots \\ x_n - x_1 & y_n - y_1 \end{bmatrix} \tag{4.4}$$

$\vec{x}$ represents the estimated location of the target.

The distance between the coordinates of $AP_i$ and $AP_j$ is denoted as $d_{ij}$ and j is the reference access point number.

$$d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{4.5}$$

However, the first constraint (j=1) is selected for linearizing, even of them could be used. There are n number of APs, tehrefore there will be a linear system of (n-1) equations [58]. Since there are 6 APs, there will be 5 equations. Thus, $d_{21}$, $d_{31}$, ..., $d_{n1}$ will be calculated.

Formula 4.5 used in calculating the vector $\vec{b}$ , as shown in Equation 4.6.

$$\vec{b} = \begin{bmatrix} b_{21} \\ b_{31} \\ \vdots \\ b_{n1} \end{bmatrix} = \begin{bmatrix} \frac{1}{2}(r_1^2 - r_2^2 + d_{21}^2) \\ \frac{1}{2}(r_1^2 - r_3^2 + d_{31}^2) \\ \vdots \\ \frac{1}{2}(r_1^2 - r_n^2 + d_{n1}^2) \end{bmatrix} \tag{4.6}$$

The estimated location of the target can be obtained by the formula;

$$A^T A\vec{x} = A^T\vec{b} \tag{4.7}$$

Where $A^T$ is the transpose of matrix A

$$A^T = \begin{bmatrix} x_2 - x_1 & x_3 - x_1 & \cdots & x_n - x_1 \\ y_2 - y_1 & y_3 - y_1 & \cdots & y_n - y_1 \end{bmatrix} \tag{4.8}$$

$$\vec{x} = \begin{bmatrix} x_b \\ y_b \end{bmatrix} \tag{4.9}$$

Solving $\vec{x}$ vector, gives the coordinates of the beacon. The algorithm of the LLS is presented in Table 4.5.

**Table 4.5:** Linear least squares algorithm.

| **Algorithm: Linear Least Squares Algorithm** |
|---|
| **Input:** $r_i$ for i=1 to 6 ← radius of APs |
| $x_i$, $y_i$ for i=1 to 6 ← coordinates of Aps |
| **Output:** ($x_b$, $y_b$) ← estimated coordinate of Beacon |
| |
| **begin** |
| j=1 ← Select linearizing constraint |
| Construct matrix A by Equation 4.4 |
| Take transpose of matrix A by Equation 4.8 |
| Calculate $d_{ij}$ for 5 APs by Equation 4.5 |
| Construct vector $\vec{b}$ with r and $d_{ij}$ values by Equation 4.6 |
| *Using Formula:* $A^T A\vec{x} = A^T\vec{b}$ Solve for $\vec{x}$ |
| **return** ($x_b$, $y_b$) |
| **end** |

### 4.2.2.3 Newton Raphson iteration

Newton Raphson is a numerical search algorithm which minimizes the sum of the square errors for optimization of the non linear least squares problem. The method requires an initial estimated value as input and then computes subsequent iterates.

Before applying the Newton Raphson method, the non linear functions which are the exact distances should be calculated with Formula in 4.10.

The z-axis is neglected in the calculations because a 2-dimensional test is being performed in the study.

$$(x - x_i)^2 + (y - y_i)^2 = \hat{r}_i^2 \tag{4.10}$$

$x_i$ = x coordinate of ith AP

$y_i$ = y coordinate of ith AP

x = estimated x coordinate of beacon

y = estimated y coordinate of beacon

$\hat{r}_i$ = Calculated distance from RSSI

$$f_i(x, y) = \hat{r}_i - r_i \tag{4.11}$$

$r_i$ = calculated distance between target and APs.

The error function F(x,y) ,which is to be minimized, is the summation of $f_i(x, y)$ for each AP;

$$F(x,y) = \sum_{i=1}^{n} f_i(x,y)^2 = \sum_{i=1}^{n} (\hat{r}_i - r_i)^2 \tag{4.12}$$

$$F(x,y) = \sum_{i=1}^{n} (\sqrt{(x-x_i)^2 + (y-y_i)^2} - r_i)^2 \tag{4.13}$$

Minimizing F(x,y) requires taking the derivatives with x and y respectively.

$$\frac{\partial F}{\partial x} = 2\sum_{i=1}^{n} f_i \frac{\partial f_i}{\partial x} \quad , \quad \frac{\partial F}{\partial y} = 2\sum_{i=1}^{n} f_i \frac{\partial f_i}{\partial y} \tag{4.14}$$

The vectors $\vec{f}$ and $\vec{g}$ are as follows;

$$\vec{g} = \begin{bmatrix} \frac{\partial F}{\partial x} \\ \frac{\partial F}{\partial y} \end{bmatrix} \quad , \quad \vec{f} = \begin{bmatrix} f_1 \\ f_2 \\ \vdots \\ f_n \end{bmatrix} \tag{4.15}$$

$\vec{f}$ is a vector which is composed of the functions $\vec{f_i}(x,y)$ for all AP.

$$\vec{g} = 2J^T\vec{f} \tag{4.16}$$

The Jacobian matrix which is the derivative of $\vec{f_i}$ functions with respect to x and y [57] is used to solve nonlinear equations by iterative methods. Matrix columns are composed of variables and rows are composed of functions.

$$J = \begin{bmatrix} \frac{\partial f_1}{\partial x} & \frac{\partial f_1}{\partial y} \\ \frac{\partial f_2}{\partial x} & \frac{\partial f_2}{\partial y} \\ & \vdots & \\ \frac{\partial f_n}{\partial x} & \frac{\partial f_n}{\partial y} \end{bmatrix} \tag{4.17}$$

In our system, n is equal to 6, and there are two variables. Therefore, $J^TJ$ is a (2x2) matrix and presented by Equation 4.17.

$$J^T J = \begin{bmatrix} \sum_{i=1}^{n} \frac{(x - x_i)^2}{(f_i + r_i)^2} & \sum_{i=1}^{n} \frac{(x - x_i)(y - y_i)}{(f_i + r_i)^2} \\ \sum_{i=1}^{n} \frac{(x - x_i)(y - y_i)}{(f_i + r_i)^2} & \sum_{i=1}^{n} \frac{(y - y_i)^2}{(f_i + r_i)^2} \end{bmatrix} \tag{4.18}$$

$$J^T \vec{f} = \begin{bmatrix} \sum_{i=1}^{n} \frac{(x - x_i) f_i}{(f_i + r_i)} \\ \sum_{i=1}^{n} \frac{(y - y_i) f_i}{(f_i + r_i)} \end{bmatrix} \tag{4.19}$$

Newton Raphson iteration is presented in the below Equation 4.20:

$$\vec{R}_{\{k+1\}} = \vec{R}_{\{k\}} - (J_{\{k\}}^T J_{\{k\}})^{-1} J_{\{k]}^T \vec{f}_{\{k\}} \tag{4.20}$$

$\vec{R}_{\{k\}}$ refers to kth approximate solution and $\vec{R}_{\{k+1\}}$ is the new iteration. Initial condition $\vec{R}_{\{k\}}$ is obtained from average trilateration or LLS calculations [57].

The explicit form of Newton Raphson method in 2 dimensional form is given in Equation 4.21.

$$\begin{bmatrix} x_{k+1} \\ y_{k+1} \end{bmatrix} = \begin{bmatrix} x_k \\ y_k \end{bmatrix} - \begin{bmatrix} \sum_{i=1}^{n} \frac{(x-x_i)^2}{(f_i+r_i)^2} & \sum_{i=1}^{n} \frac{(x-x_i)(y-y_i)}{(f_i+r_i)^2} \\ \sum_{i=1}^{n} \frac{(x-x_i)(y-y_i)}{(f_i+r_i)^2} & \sum_{i=1}^{n} \frac{(y-y_i)^2}{(f_i+r_i)^2} \end{bmatrix}^{-1} \begin{bmatrix} \sum_{i=1}^{n} \frac{(x-x_i) f_i}{(f_i+r_i)} \\ \sum_{i=1}^{n} \frac{(y-y_i) f_i}{(f_i+r_i)} \end{bmatrix} \tag{4.21}$$

If the first estimate is consistent, the Newton Raphson method finds the corresponding value from the derivative of the function according to the estimates. The previous estimate is revised in the new iteration and generally 3$^{rd}$ iteration is enough to achieve solution. Algorithm of the method is represented in Table 4.6.

**Table 4.6:** Newton Raphson algorithm.

```
Algorithm: Newton Raphson Algorithm

Input: r_i for i=1 to 6 ← Calculated radius of APs
       x_i, y_i for i=1 to 6 ← Coordinates of Aps
       x, y ← Estimated coordinates of Beacon
Output: (x_b, y_b) ← Estimated coordinate of Beacon

begin
  iteration=3
  n= 6
  for iteration=1 to 3 do
    for i=1 to n do
      Calculate r̂_i by Equation 4.10
      Calculate f_i by Equation 4.11
    end for
    Calculate Σ_{i=1}^{n} (x−x_i)^2 / (f_i+r_i)^2
    Calculate Σ_{i=1}^{n} (x−x_i)(y−y_i) / (f_i+r_i)^2
    Calculate Σ_{i=1}^{n} (y−y_i)^2 / (f_i+r_i)^2
    Construct J^T J matrix by Equation 4.18
    Take inverse of J^T J matrix
    Calculate Σ_{i=1}^{n} (x−x_i) f_i / (f_i+r_i)
    Calculate Σ_{i=1}^{n} (y−y_i) f_i / (f_i+r_i)
    Construct J^T f⃗ matrix by Equation 4.19
    Using Newton iteration by Equation 4.21 calculate R⃗_{k+1}
    x=x_b and y=y_b
  end for
  return (x_b, y_b)
end
```

### 4.2.3 Tests and Results

The test samples used throughout the study are described in detail below. The graph of sample data collected simultaneously by all access points from a test is shown in Figure 4.17. As can be seen from the graph, although the peaks in the signal were eliminated, the RSSI values vary continuously due to the high noises on the signal. This variation reached up to approximately 35 dBm. So, the mean values of the filtered datasets were used in position finding.

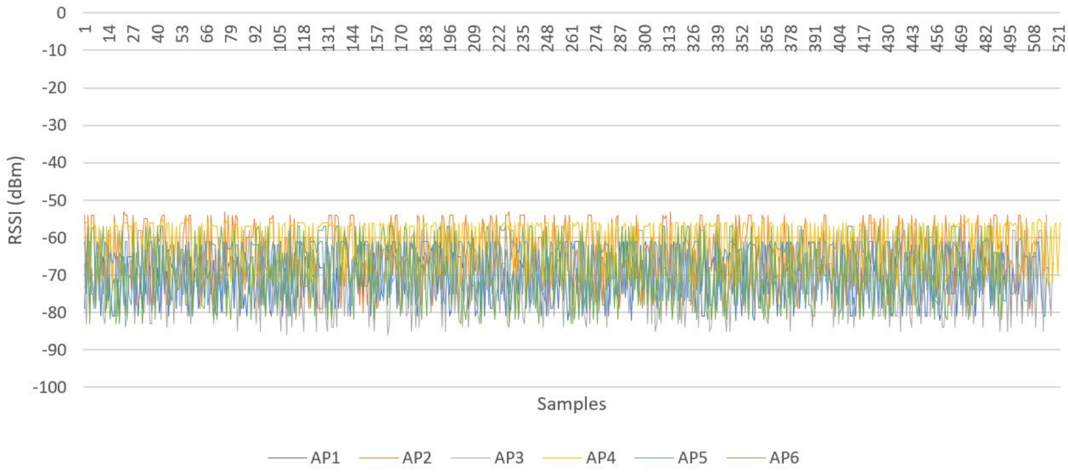



**Figure 4.15:** RSSI values of six AP

Many different tests have been carried out in the environment. In a test, the estimated distance which is calculated by means of the average values obtained from the signals is presented in Figure 4.18.

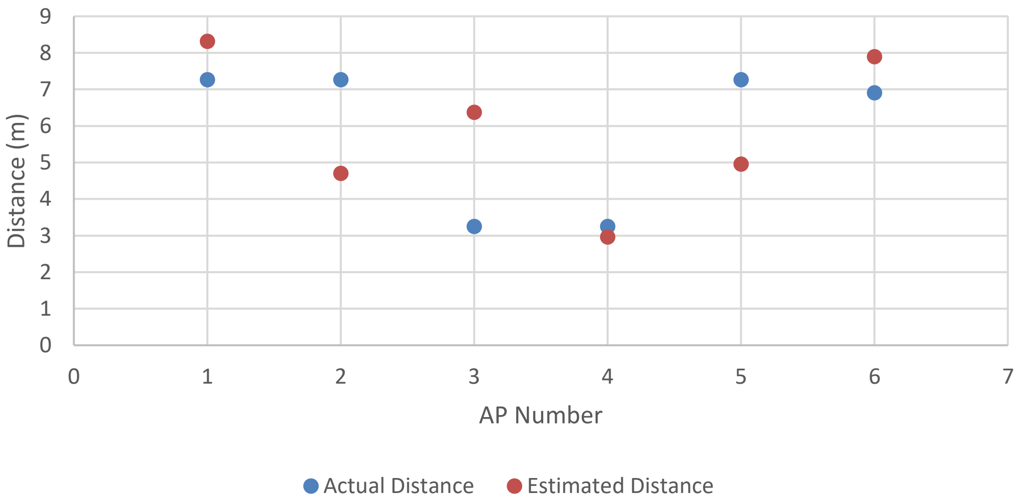



**Figure 4.16:** Actual and estimated distances of Beacon

Some of the estimates are close to the actual values, while others are far away. This is due to the difference in the received signal strength. Figure 4.19 shows the circles drawn with the radii calculated from the RSSI values.

For verification, the distance was calculated between the estimated point and the actual position of the transmitter. The best intersection was obtained with a difference of 1.12 meters and as seen in Figure 4.20.

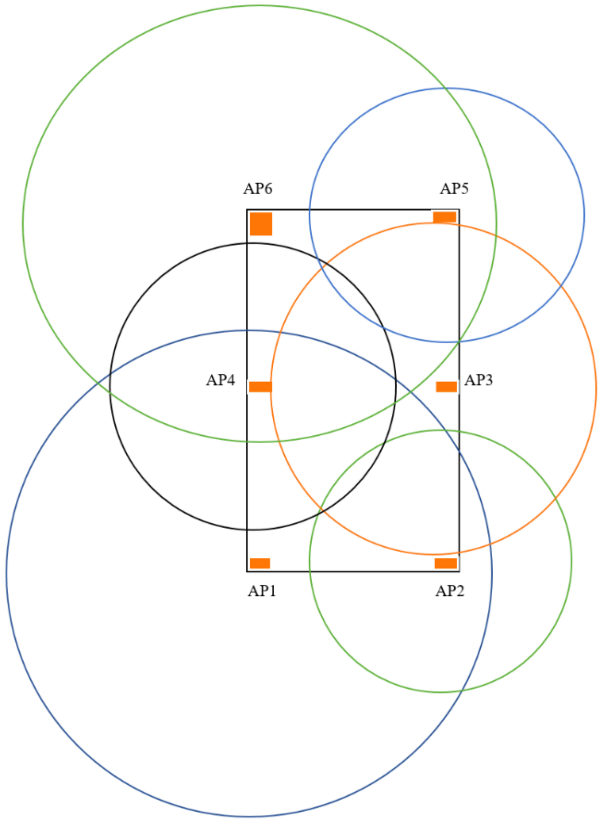



**Figure 4.17:** Circles of Test.1

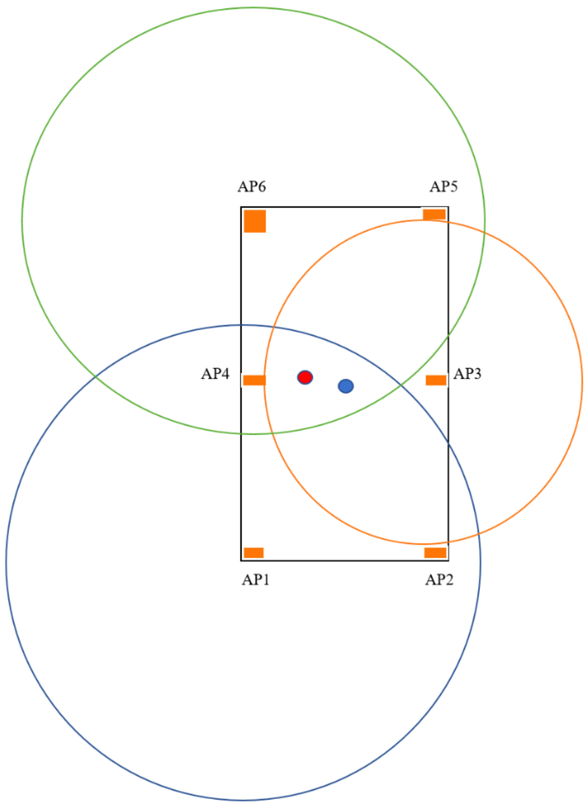



**Figure 4.18:** Best intersection of Test.1

All intersections was reduced to a single position by the average calculation. The estimate was closer than the above-mentioned best intersection. Increasing the number of access points had a positive effect on the accuracy of the system in which the distance between the estimated and actual point is 0.12 meters. This estimate was recalculated with the Newton Raphson iteration described in 4.2.2.3 and the error was decreased to 0.11 meters. Table 4.7 gives the results of this test.

**Table 4.7:** Comparison of Test.1 results.

| Positions | X | Y |
|---|---|---|
| Actual Position | 3.25 | 6.5 |
| Average of Trilateration | 3.37 | 6.49 |
| Newton Raphson with Trilateration | 3.16 | 6.43 |
| Linear Least Squares | 5.03 | 6.72 |
| Newton Raphson with LLS | 3.15 | 6.45 |

In this test linear least squares method calculated the position worse than average trilateration. Hence, Newton Raphson iteration has been applied with the estimate and in the 3rd iteration, a difference of 0.11 m was reached.

Another test result is presented in Figure 4.21. When this drawing is analyzed, it could be seen that there are more intersections. Newton Raphson iteration with average of triangulation was reached to 0.91 meter difference between the actual point and the estimated point. After 3rd iteration, the difference decreased to 0.5 meters.

Newton Raphson iteration with linear least squares estimate results 0.46 meter difference again in the 3rd iteration. If more iterations are applied, these values will be further reduced to 0.43 meter difference. All estimates of the test can be seen in Table 4.8.

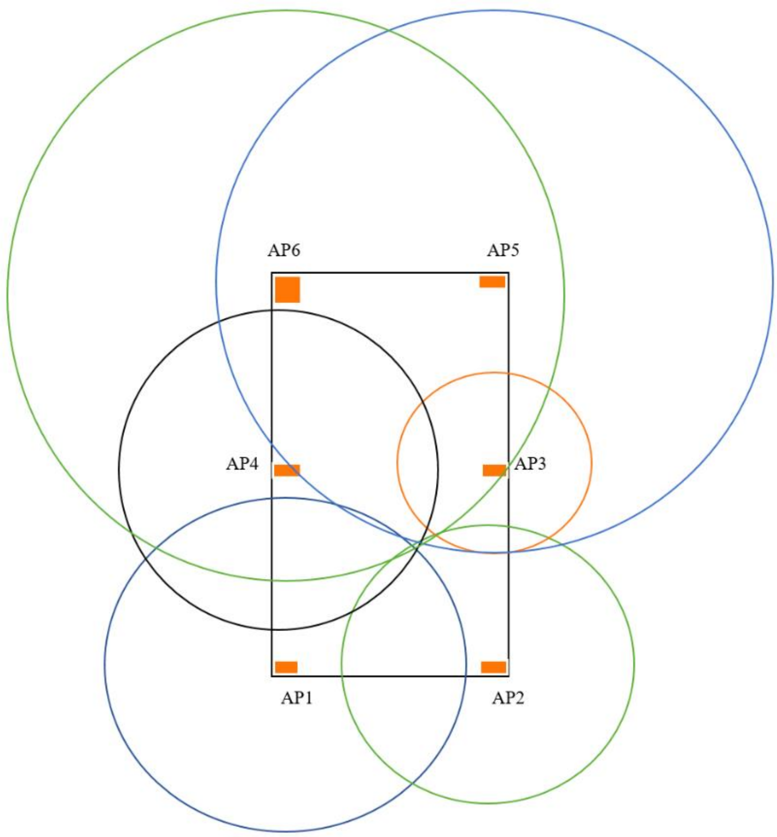



**Figure 4.19:** Circles of Test.2

**Table 4.8:** Comparison of Test.2 results.

| Positions | X | Y |
|---|---|---|
| Actual Position | 4.2 | 4.5 |
| Average of Trilateration | 3.25 | 6.18 |
| Newton Raphson with Trilateration | 3.79 | 6.89 |
| Linear Least Squares | 5.15 | 6.03 |
| Newton Raphson with LLS | 3.82 | 4.86 |

The results of the last test can be seen in Figure 4.22.

When the radii of the APs' calculated, it was seen that the conflicts are concentrated in the upper part of the test area. The position of the device with average trilateration method is 2.51 m away from the actual position. With linear least square estimation, distance was calculated 2.2 meters. After applying Newton Raphson iteration to both results, the distance decreased to 2.13 in further iterations.

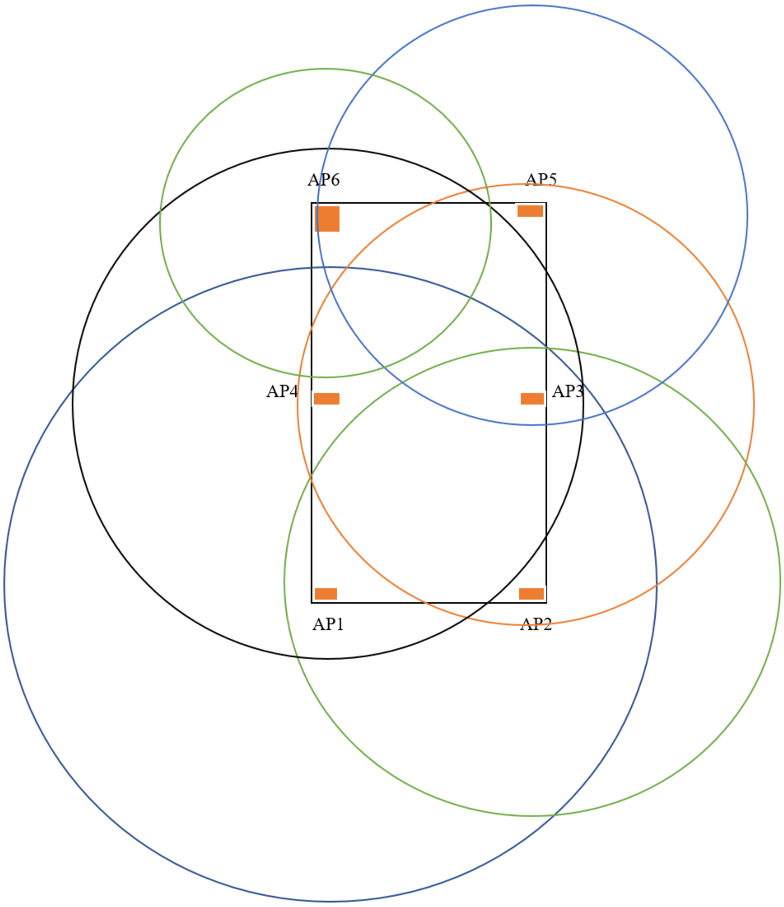



**Figure 4.20:** Circles of Test.3

The estimates of the Test 3 is presented in Table 4.9.

**Table 4.9:** Comparison of Test.3 results.

| Positions | X | Y |
|---|---|---|
| Actual Position | 3.25 | 9 |
| Average of Trilateration | 5.75 | 8.82 |
| Newton Raphson with Trilateration | 5.73 | 10.12 |
| Linear Least Squares | 5.43 | 8.71 |
| Newton Raphson with LLS | 5.43 | 10.19 |

During these studies, the moving object tests was considered too. These tests were estimated on time bases. The simultaneously read data was averaged for all access points in second bases. First, the distance calculation was done with the average values of RSSI at a second. With the radius values, the system checked the intersections of the radii and calculated the estimated points of trilateration. The average of those values was reduced to a single solution. Later estimated values were optimized with Newton Raphson method. Afterwards, position estimation was performed using linear least squares and optimized again with Newton Raphson iteration. However, a satisfactory result was not obtained. The main reason of this result is the scarcity of data read in seconds. Two data per second is not sufficient for successful position estimation for moving tests, because the average of more data is needed for consistent results with the RSSI.

# 5. CONCLUSION AND FUTURE WORKS

Indoor positioning based on Bluetooth has been reviewed and implemented during this master thesis. It is aimed to establish a low-cost system that will save people or objects from necessity to carry mobile devices. The PLC laboratory of Bursa Technical University was selected for implementation of the study.

Position estimation was made by evaluating the calculated radius values from the resulting RSSI with two different methods. Position estimation is performed using the well-known trilateration method. Addition to trilateration method, linear least squares algorithm and Newton Raphson iteration are evaluated for increasing accuracy. In the studies carried out for the analysis of the RSSI signal, it has been seen that the signal transmitter and receiver antenna direction, ambient conditions, altitude, dynamic environment and transmitter power level have negative impacts on indoor positioning accuracy.

The mean values of the RSSI were used both in calibration and tests. In the tests performed at different angles within 1meter distance, the signal was changed approximately between 15 to 17 dBm. This change causes big differences in the distance estimation.

In the tests for observation of RSSI signal variation, the receiver was positioned horizontally on a 1.5 meter high plane. The average of the RSSI readings was taken up to 10 meters and 10 signal values collected in a second. It was observed that the RSSI value starts around -72 dBm. However, when the receiver was placed vertically on a wall with 2 meters high from the floor and 2 signals were collected per second, the level of the signal started round -50 dBm. This shows the effect of the obstacles in indoor environment.

Initial tests were carried out in a smaller area by using values from only 3 APs. Estimation was done by using trilateration. In cases where there is no intersection of circles, the position calculation is made by adding the standard deviation values calculated in the calibration phase. However, these were found to be inadequate. The area was expanded, and the number of AP was increased.

Some tests showed that when LNS and ambient conditions deteriorate, the estimated distance increases too much. This caused a big deviation in estimated position from the real position of the target.

The results of the tests performed during the study showed that, the difference between the estimated position and the actual point changes between 0.11 to 2.2 meter due to the RSSI readings. Since the tree intersected radii are considered and others eliminated by the system, the average trilateration estimation yields realistic results with Newton Raphson iteration. When the radii of the APs showed a correct distribution and more intersection, it was observed that Newton Raphson iteration with linear least squares gave more accurate results. These results are substantial for the stationary or delayed-action objects, because it was seen that position estimation of the moving object with only RSSI is not enough.

Hybrid solutions can be tried for increasing the accuracy of moving tests as a future work. Also, radii of the circles would be checked and compared with determined tresholds to obtain accurate solutions before applying both methods. Standard deviations can also be included in the calculations. It is thought that this will provide a more accurate solution for position estimation. In this study, test environment is limited to a single laboratory. Future work would be performed in a large area with more access points.

**REFERENCES**


**[1] Curran, K., Furey, E., Lunney, T., Santos, J., Woods, D., Mc Caughey, A.,** (2011). An Evaluation of Indoor Location Determination Technologies. *Journal of Location Based Service, 5,* 61-78, doi:10.1080/17489725.2011.562927.

**[2] Kajioka, S., Mori T., Uchiya T., Takumi I., Matsuo H.,** (2014). Experiment of Indoor Position Presumption Based on RSSI of Bluetooth LE Beacon, *IEEE 3rd Global Conference on Consumer Electronics (GCCE),* (pp. 337-339). Tokyo, Japan, Oct 7-10.

**[3] Han, J., Zhao, Y., Cheng, Y., S., Wong, T., L., Wong, C., H.,** (2012). Improving Accuracy for 3D RFID Localization. *International Journal of Distributed Sensor Networks, 8,* 1-9, doi: 10.1155/2012/865184.

**[4] Chen, T. Y., Yang, L. C., Chang, K. Y., Chu, P. C.,** (2009). RSSI-based Algorithm for Indoor Localization Using Zigbee in Wireless Sensor Netwok. *Fifteenth International Conference on Distributed Multimedia Systems,* (pp. 70-75). Boston, United States, September 10-12.

**[5] Chih-Ning, H. and Chia-Tai, C.,** (2011). ZigBee-based Indoor Location System by K-nearest Neighbor Algorithm with Weighted RSSI. *Procedia Computer Science, 5,* 58-65, doi: 10.1016/j.procs.2011.07.010.

**[6] Mahiddin, N., A., Safie, N., Nadia E., Safei S., Fadzli E.,** (2012). Indoor Position Detection Using Wi-Fi and Trilateration Technique, *The International Conference on Informatics and Applications (ICIA2012),* (pp. 362-366). Malaysia, June 3-5.

**[7] Alarifi, A., Al-Salman, A., Alsaleh, M., Alnafessah, A., Al-Hadhrami, S., Al-Ammar, M. A., Al-Khalifa, H. S.,** (2016). Ultra-Wide Band Indoor Positioning Technologies: Analysis and Recent Advances. *Sensors (Basel), 16(5),* 707, doi:10.3390/s16050707.

**[8] Dahlgren, E. and Mahmood H.,** (2014). *Evaluation of Indoor Positioning Based on Bluetooth Smart Technology,* (M. Sc. Thesis). Chalmers University of Technology, Department of Computer Science and Engineering, Goteborg, Sweden.

**[9] Rida, M. E., Liu, F., Jadi, Y., Algawhari, A. A. A., Askourih, A.,** (2015). Indoor Location Position Based on Bluetooth Signal Strength. *2nd International Conference on Information Science and Control Engineering (ICISCE), 2015,* 769-773, doi: 10.1109/ICISCE.2015.177.

**[10] Kriz, P., Maly, F., Kozel, T.,** (2016). Improving Indoor Localization Using Bluetooth Low Energy Beacons. *Mobile Information Systems, 2016,* 11, doi:10.1155/2016/2083094.

**[11] Faragher, R. and Harle, R.,** (2014). An Analysis of the Accuracy of Bluetooth Low Energy for Indoor Positioning Applications, *Proceedings of the 27th*

*International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS+ 2014),* (pp. 201-210). Tampa, Florida, September 8-12.

**[12] Organero, M. M., Merino, P. J. M., Kloos, D. C.,** (2012). Using Bluetooth to Implement a Pervasive Indoor Positioning System with Minimal Requirements at the Application Level. *Mobile Information Systems, 8(1),* 73-82, doi: 10.3233/MIS-2012-0132.

**[13] Xin-Yu, L., Tei- Wei, H., Cheng-Chung, F., Zui-Shen, Y., Bey- Jing, Y., Feipei, L.,** (2015). A Mobile Indoor Positioning Based on iBeacon Technology. *37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), 2015,* 4970-4973, doi: 10.1109/EMBC.2015.7319507.

**[14] Basak, A., A.,** (2017). *Optimization of Indoor Localization with Grid Based Fingerprinting Algorithms,* (M. Sc. Thesis). Ankara University, Graduate School of Natural and Applied Sciences Department of Electrical Electronics Engineering, Ankara.

**[15] Demiral, E.,** (2014). *RFID-Based Indoor Positioning System Design within the Scope of Three Dimensional (3D) Geographic Information Systems,* (M. Sc. Thesis). Karabuk University, Graduate School of Natural and Applied Sciences Department of Computer Engineering, Karabuk.

**[16] Rıfai, A.,** (2009). *Indoor Positioning at Arlanda Airport,* (M. Sc. Thesis). KTH Information and Communication Technology, Radio Communication Systems, Sweden.

**[17] Bayar, V.,** (2016). *The Effect of RF Signal Characteristics on Indoor Positioning,* (M. Sc. Thesis). Eskisehir Osmangazi University, Department of Electrical and Electronics Engineering, Eskisehir.

**[18] Liu, H., Darabi, H., Banerjee, P., Liu, J.,** (2007). Survey of Wireless Indoor Positioning Techniques and Systems. *IEEE Transactions on Systems, Man, and Cybernetics, Part C Applications and Reviews, 37(6),* 1067-1080, doi: 10.1109/TSMCC.2007.905750.

**[19] Baniukevic, A., Jensen, C., S., Lu H.,** (2013). Hybrid Indoor Positioning with Wi-Fi and Bluetooth: Architecture and Performance. *IEEE 14th International Conference on Mobile Data Management, 1,* 207-216, doi: 10.1109/MDM.2013.30.

**[20] Namuduri, K. and Costilla-Reyes, O.,** (2014). Dynamic Wi-Fi Fingerprinting Indoor Positioning System. *2014 International Conference on Indoor Positioning and Indoor Navigation (IPIN).* (pp. 271-280), Busan, October 27-30.

**[21] Dong, G., Lin, K., Li, K., Luo, H., Zhang, X.,** (2014). FMA-RRSS: Fingerprint Matching Algorithm Based on Relative Received Signal Strength in Indoor Wi-Fi Positioning. *IEEE 17th International Conference on Computational Science and Engineering (CSE),* (pp. 1071-1077). Chengdu, China, December 2014.

**[22] Dao, H. T., Nguyen, C. Q., Ngo, D. V., Le, T. M., Hoang, A. C,** (2014). Indoor Localization System based on Passive RFID Tags, *2014 Fifth International Conference on Intelligent Systems, Modelling and Simulation,* (pp. 579-584). Langkawi, Malaysia, Jan. 27-29.

**[23] Umar, A.,** (2015). *iBeacon Localization,* (M. Sc. Thesis). Eindhoven University of Technology, Department of Mathematics and Computer Science, Eindhoven.

**[24] Yavari, M.,** (2014). *Ultra Wideband Wireless Positioning Systems,* (M. Sc. Thesis). Faculty of Computer Science University of New Brunswick, Canada.

**[25] Mautz, R.,** (2012). *Indoor Positioning Technologies*, (Habilitation Thesis). ETH Zurich Institute of Geodesy and Photogrammetry, Department of Civil, Environmental and Geomatic Engineering, Zurich.

**[26] Zhetao, L., Renfa, L., Yehua, W., Tingrui, P.,** (2010). Survey of Localization Techniques in Wireless Sensor Networks. *Information Technology Journal, 9(8),* 1754-1757, doi: 10.3923/itj.2010.1754.1757.

**[27] Özdemir, B. N., Ceylan, A., Alçay, S., Yigit, C. Ö.,** (2014). Comparison of The Various Indoor Positioning Methods, *7th National Engineering Measurements Symposium*, Çorum: Hitit University, October 15-17.

**[28] Sakpere, W., Adeyeye-Oshin, M., Mlitwa, N.B.W.,** (2017). A state-of-the-art Survey of Indoor Positioning and Navigation Systems and Technologies. *South African Computer Journal, 29(3),* 145-197, doi:10.18489/sacj.v29i3.

**[29] Engström, H., Helander, F.,** (2015). *Evaluation and Testing of Techniques for Indoor Positioning,* (M. Sc. Thesis). Department of Electrical and Information Technology Faculty of Engineering, Lund University, Sweden.

**[30] Salamah, A. H., Tamazin, M., Sharkas, M. A., Khedr, M.,** (2016). An Enhanced WiFi Indoor Localization System Based on Machine learning, 2016 International Conference on Indoor Positioning and Indoor Navigation (IPIN), (pp. 1-8), Madrin, Spain, October 4-7.

**[31] Youssef, M., Agrawala, A.,** (2005). The Horus WLAN Location Determination System, *Proceedings of the 3rd International Conference on Mobile Systems, Applications and Services,* (pp. 205-218). Seattle, Washington, June 6-8.

**[32] Navarro, E., Peuker, B., Quan, M. A., Jipson, D. J.,** (2010). *Wi-Fi Localization Using RSSI Fingerprinting*. Computer Engineering Department, California Polytechnic State University:, CA: San Luis Obispo. Available online: https://digitalcommons.calpoly.edu/cpesp/17/ (accessed on 2 May 2017).

**[33] Altıntas, B.,** (2013). *Improvement of RSS-Based Indoor Positioning System by Enhancing Location Sensing Algorithms,* (M. Sc. Thesis). Yeditepe University Department of Computer Engineering, Yeditepe University, Istanbul.

**[34] Pahlavani, P., Gholami, A., Azimi, S.,** (2017). An Indoor Positioning Technique Based on a Feed-Forward Artificial Neural Network Using Levenberg Marquart Learning Method, *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-4/W4,* 435-440, doi: 10.5194/isprs-archives-XLII-4-W4-435-2017.

**[35] Feng, Y., Minghua J., Jing L., Xiao, Q., Ming, H., Tao, P., Xinrong, H.,** (2014). An Improved Indoor Localization of WiFiBased On Support Vector Machines. *International Journal of Future Generation Communication and Networking, 7(5),* 191-206, doi: 10.14257/ijfgcn.2014.7.5.16.

**[36] Altintas, B., Serif, T.,** (2011). Improving RSS-Based Indoor Positioning Algorithm via K-Means Clustering, *17th European Wireless 2011 – Sustainable Wireless Technologies,* (pp. 1-5). Vienne, Austria, April 27-29.

**[37] Perente, K, O., Çelikel, K., Serif, T.,** (2015). Bina İçi Yer Belirleme Saha Çalışması: Geniş Mekânda Yer İşaretleme Yöntemiyle Konum Tespitinde Sinyal

Çıkış Güçlerinin Etkisinin Karşılaştırılması, *İnet-Tr'15, XX. Türkiye'de İnternet Konferansı,* (pp. 114-119). İstanbul, Turkey, December 1-3.

**[38] Kajioka, S., Mori, T., Uchiya, T., Takumi, I., Matsuo, H.,** (2014). Experiment of Indoor Position Presumption Based on RSSI of Bluetooth LE Beacon, *IEEE 3rd Global Conference on Consumer Electronics (GCCE)*, (pp. 337-339). Tokyo, Japan, October 7-10.

**[39] Chraibi, Y.,** (2005). *Localization in Wireless Sensor Networks*, (M. Sc. Thesis). KTH Royal Institute of Technology, Signals Sensors and Systems, Stockholm, Sweden.

**[40] Akgul, F., Heidari, M., Alsindi, N., Pahlavan, K.,** (2009). Localization Algorithms and Strategies for Wireless Sensor Networks: Monitoring and Surveillance Techniques for Target Tracking. *Localization Algorithms and Strategies for Wireless Sensor Networks,* Chapter 3, 54-95, doi:10.4018/978-1-60566-396-8.ch003.

**[41] Shen, G., Zetik R., Yan, H., Thomä, R. S.,** (2010). Time of Arrival Estimation for Range Based Localization in UWB Sensor Networks. *IEEE International Conference on Ultra-Wideband (ICUWB), 2,* 20-23, doi: 10.1109/ICUWB.2010.5614041.

**[42] Dari, Y., Suyoto, S., Pranow, P.,** (2018). CAPTURE: A Mobile Based Indoor Positioning System using Wireless Indoor Positioning System. *International Journal of Interactive Mobile Technologies*, *12*, 61-72, doi:10.3991/ijim.v12i1.7632.

**[43] Braggaar, R., C.,** (2018). *Wi-Fi network-based indoor localisation The case of the TU Delft Campus*, (M. Sc. Thesis), Geomatics for the Built Environment, Delft University of Technology, Netherlands.

**[44] Kaluža, M., Beg, K., Vukelić, B.,** (2017). Analysis of an Indoor Positioning Systems, *Zbornik Veleučilišta u Rijeci, 5(1),* 13-32, doi: 10.31784/zvr.5.1.2.

**[45] Bahl, P., and Padmanabhan, V. N.,** (2000). RADAR: An In-Building RF-Based User Location and Tracking System, *Proceedings of IEEE Infocom 2000*, (pp. 775–784). Tel-Aviv, Israel, March 26-30.

**[46] Priyantha, B. N.,** (2005). *The Cricket Indoor Location System* (Ph.D. Thesis). Massachusetts Institute of Technology, Department of Electrical Engineering and Computer Science, Cambridge.

**[47] Harter, A., Hopper, A., Steggless, P., Ward, A., Webster, P.,** (2002). The Anatomy of a Context-Aware Application. *Wireless Networks*, 8(2). 187-197, doi: 10.1023/A:1013767926256.

**[48] LaMarca, A., Chawathe, Y., Consolvo, S., Hightower, J., Smith, I., Scott, J., Sohn, T., Howard, J., Hughes, J., Potter, F., Tabert, J., Powledge, P., Boriello, G., Schilit, N. B.,** (2005). Place Lab: Device Positioning Using Radio Beacons in the Wild, *Pervasive 2005: Third International Conference on Pervasive Computing*, (pp. 116-133). Munich, Germany, May 8-13.

**[49] Hii, P., and Zaslavsky, A.,** (2005). Improving Location Accuracy by Combining WLAN Positioning and Sensor Technology, *Proceedings of the Workshop on Real-World Wireless Sensor Networks*, Stockholm, Sweden: Swedish Institute of Computer Science, June 20-21.

**[50] Ni, M., L., Patil, P., A.,** (2003). Landmarc: Indoor location sensing using active RFID. Wireless Networks. *Special Issue on Pervasive Computing and Communications, 10*, 407- 415, doi: 10.1109/PERCOM.2003.1192765.

**[51] Alnafessah, A., Al-Ammar, M., Alhadhrami, S., Al-Salman, A., Al-Khalifa, H.,** (2016). Developing an Ultra Wideband Indoor Navigation System for Visually Impaired People. *International Journal of Distributed Sensor Networks, 12(7)*, 6152342-6152342, doi:10.1177/155014776152342.

**[52] Indoo.rs,** [Online]. Accessed: 18 October 2018, https://www.indoo.rs/

**[53] Indoor Atlas,** [Online]. Accessed: 18 October 2018, https://www.indooratlas.com/

**[54] Paek, J., Ko, J., Shin, H.,** (2016). A Measurement Study of BLE iBeacon and Geometric Adjustment Scheme for Indoor Location-Based Mobile Application. *Mobile Information Systems, 2016*, 1-13, doi: 10.1155/2016/8367638.

**[55] Raghavan, N., A., Ananthapadmanaban, H., Sivamurugan, S. M., Ravindran, B. S.,** (2010). Accurate Mobile Robot Localization in indoor environments using Bluetooth**.** *IEEE International Conference on Robotics and Automation (ICRA), 2010*, 4391-4396, doi: 10.1109/ROBOT.2010.5509232.

**[56] Paterna, C. V., Augé, C. A., Aspas, P. J., Bullones, P. A. M.,** (2017). A Bluetooth Low Energy Indoor Positioning System with Channel Diversity, Weighted Trilateration and Kalman Filtering. *Sensors (Basel), 17(12)*, 203-428, doi: 10.3390/s17122927.

**[57] Murphy, S. W. Jr., Hereman. W.,** (1995). Determination Of A Position In Three Dimensions Using Trilateration and Approximate Distances, *Decision Sciences.*

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